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U.S. Department of Energy Guidebook on Commercialized Energy Efficiency and Supply Technologies for the Glass Manufacturing Industry

U.S. Department of Energy
Energy Efficiency and Renewable Energy

Disclaimer

U.S. Department of Energy Guidebook on Commercialized Energy Efficiency and Supply Technologies for the Glass Manufacturing Industry

Prepared for the
Industrial Technologies Program
U.S. Department of Energy

by

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under contract DE-AC01-01EE41417
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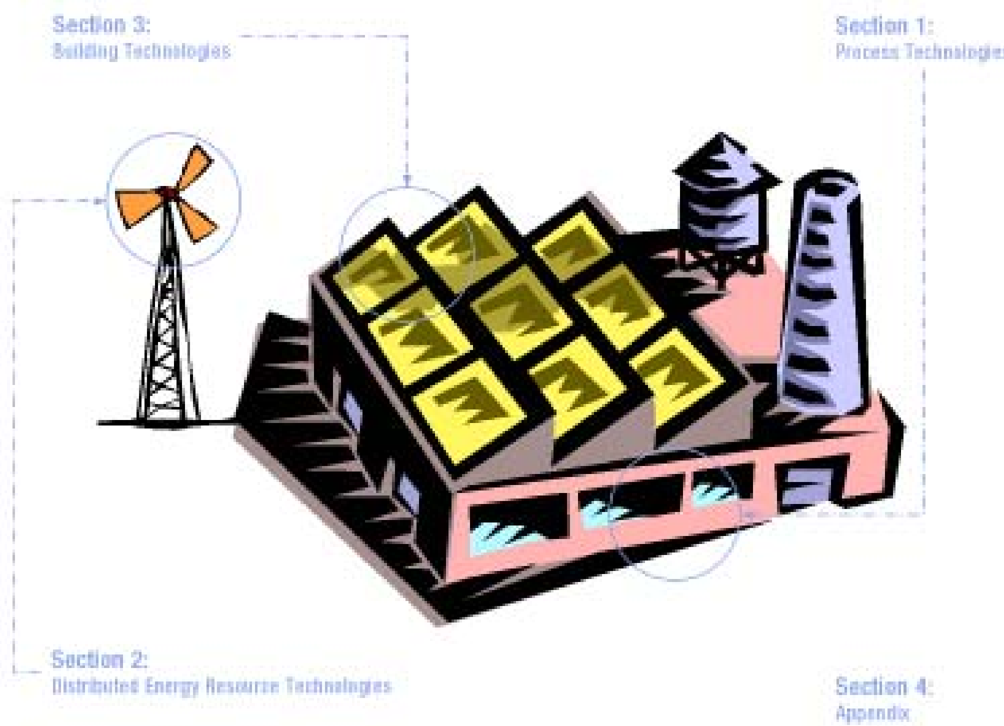
Introduction



What?

This "Guidebook" to energy technologies for the glass manufacturing industry lists and describes a variety of technologies that energy managers in the glass industry can use to make their plants more efficient, self-reliant, profitable, and less polluting.

Who?

The U.S. Department of Energy Industrial Technologies Program prepared this guide to energy technologies that the Department of Energy Office of Energy Efficiency and Renewable Energy has helped develop.

Why?

An introductory reference, the Guide will steer glass plant facility managers to new energy-saving and supply options they may not know are available. Besides manufacturing technologies the Office of Industrial Technologies has developed, the Guidebook includes many other technologies that have emerged from DOE programs that glass manufacturers can consider for their facilities.

How?

The Guide has three main technical sections:

1. Glass Manufacturing Process Technologies;
2. On-Site Electric and Thermal Energy Generation Technologies; and
3. Building Technologies Applicable to Plant Facilities.

How Much?

For each technology, the Guide provides the following information:

- Technology Description;
- Economic Profile;
- Environmental Profile;
- Market Status;
- Technology Outlook; and
- DOE Program Contacts for Additional Information

The Guide also includes summary information on:

- Regulatory and utility policies that affect energy project implementation;
- Local, state, utility, and federal incentives available for many technologies; and
- Basic information on life-cycle costing.

Introduction to the Guidebook

Many new energy conservation and supply options are available and competitive for industrial plants; however, trustworthy information about them is not always easy to find. The "U.S. Department of Energy Guidebook on Commercialized Energy Efficiency and Supply Technologies for the Glass Manufacturing Industry" is an introductory reference that will help glass plant managers and operators learn more about technology options they may have overlooked. Besides a number of glass process technologies the Department of Energy's Industrial Technologies Program has developed, this Guidebook highlights other technologies that have emerged from a variety of DOE energy conservation and renewable energy programs.

Cutting-edge technologies to reduce energy costs and environmental emissions and maintain production and quality

Almost every technology in this report is commercially available. Only a few are at a pre-commercial or early demonstration stage of development. Technologies in this report are organized into three categories:

- Industrial processes;
- Distributed generation & thermal energy systems; and
- Manufacturing buildings.

For each technology featured, the Guidebook provides a description, lists applications, summarizes the economics of cost and savings, indicates its environmental impact and market status, and provides first-level contact information. Appended sections have background information on regulatory and economic issues to characterize the opportunities and risks associated with implementing these technologies.

The Office of Energy Efficiency and Renewable Energy (EERE), U.S. Department of Energy, funds technology development and disseminates unbiased expert information to facilitate adoption of technologies that increase energy efficiency, reduce pollution and waste, and employ renewable energy resources. The EERE technology development program for glass manufacturing companies is managed by the Industrial Technologies Program (ITP). This Guidebook not only features ITP technologies, it adds many other relevant technologies from the EERE RD&D portfolio.

EERE Technologies

The Office of Energy Efficiency and Renewable Energy (EERE) invests in high-risk, high-value research and development critical to the Nation that would not be sufficiently supported by the private sector alone. In addition, it also works with stakeholders to develop programs and policies to facilitate the deployment of advanced clean energy technologies and practices. EERE Technology Development Programs include:

- Biomass;
- Buildings Technology;
- Distributed Generation;
- Federal Energy Management;
- FreedomCAR and Vehicle Technologies;
- Hydrogen, Fuel Cells, and Infrastructure Technologies;
- Industrial Technologies;
- Solar Energy Technologies;
- Weatherization and Intergovernmental; and
- Wind and Hydropower Technologies.

Process Technologies

The Department of Energy Industrial Technologies Program has focused its technology development support on the most energy-intensive industries in the United States. The program takes into account the need to ensure that R&D resources are strategically allocated to maximize benefits for industry. The Department of Energy funding goes to selected R&D projects that address industry-defined priorities as well as national goals for energy and the environment. Projects focus on potentially high-payoff technologies that are too risky or costly to attract adequate private funding.

The Industrial Technologies Program awards cost-shared funding for R&D projects through a competitive solicitation process. Collaborative partnerships perform the projects, and they must address industry-specified priorities. In this way, EERE maintains a balanced portfolio of R&D projects that helps realize national goals to boost industrial productivity, conserve energy and protect the environment. The Industrial Technologies Program's success has come from following a consistent path to:

- Set a vision for the future;
- Define R&D priorities in a technology roadmap;
- Develop a portfolio of innovative R&D;
- Tap into expanded tools and resources; and
- Accelerate progress toward major technology improvements.

The program stays focused on four technical elements.

- Production Efficiency – undertake research and development that will help the industry become more efficient, productive, and competitive.

- **Energy Efficiency** – identify and pursue technology that can reduce the gap between current process energy use and the theoretical minimum.

- **Environmental Performance** – achieve cleaner operations with lower environmental control costs and increased glass recycling.

- **Innovative Uses** – develop new applications for glass that reflect a higher technical content and positively impact the industry.

The EERE Glass Industry portfolio currently comprises more than fifteen projects. The Guidebook highlights those that have emerged successfully, plus several cross-cutting technologies applicable for glass manufacturing plants.

New, improved technologies are emerging on the commercial market today as viable alternatives to many traditional technologies utilized in a glass manufacturing facility. Although many of the concepts behind these technologies were introduced many years ago, public and private sector investments in development activities have improved their performance to the point where they are commercially competitive today. When you take into account external costs and other mitigating factors, they become even more attractive. These can compete with traditional technologies in terms of product (output) quality, reliability, and cost while also significantly decreasing energy consumption and emission levels. The drivers for the emergence of these technologies have been innovative technology advancements, regulatory trends, environmental stewardship, and economics.

Distributed Energy Resources

The **Department of Energy Distributed Energy & Electric Reliability Program** develops and promotes application of power system technologies. The Program mission is to provide assistance on a national level to:

- Develop the "next generation" of clean, efficient, reliable, and affordable distributed energy technologies and integrate these technologies at end-user sites;

- Document the energy, economic, and environmental benefits of the expanded use of distributed energy resources and disseminate the findings widely; and

- Develop national and international standards that address infrastructure, energy delivery, institutional, and regulatory needs.

The Guidebook's Distributed Generation section covers various on-site power options the Program is investigating. These include traditional stationary power systems such as gas turbines, and diesel engines, as well as fuel cells and renewable energy options to generate power from solar and wind energy. Each technology overview includes general economic data and the outlook for additional technology advances. This section also includes renewable energy technologies that other EERE R&D offices have developed that generate electricity or thermal energy.

Building Technologies

Energy performance of a building structure not only affects utility bills, it can profoundly affect the productivity of the people who work in it. The **EERE Building Technologies Program**, plus several sister offices, develop technologies and standards that can make factory buildings more efficient and self sufficient. However, when glass plant staff predominantly focus on increasing production and sales, it is difficult to turn their attention to the small, but meaningful energy consumption related to building operations. This Guidebook introduces the reader to a wide variety of cost-saving and facility-improving technologies, from structural insulating panels and advanced lighting to solar energy systems that daylight or produce thermal energy or electricity. It reveals what applications are competitive and provides information on typical implementation costs and savings.

The Guidebook concludes with three appendices for managers wanting to implement a new technology energy project. The first covers regulatory and utility policies that affect energy project implementation. The second appendix provides information on available economic incentives (federal, state, and local) that help offset the costs of new energy installations; this appendix also summarizes the value of life-cycle cost analysis that looks beyond initial capital cost and simple payback to consider the lifetime performance of energy options. The third appendix lists Internet sites where more information on technologies in the Guidebook can be found.

The reference table on the following pages lists the technologies included in the Guidebook. The table indicates the type of energy generated or saved, the applications with key implementation considerations, incentive eligibility, and commercial status.

EERE Technologies for Glass Manufacturers

KEY:

T: Thermal E: Electricity F: Fuel EG: Electricity Generator	IPH Industrial Process Heat HVAC: Building Energy L: Light PC: Process Control	PF: Product Finishing C: Cost A: Awareness S: Site Limitations	RD&D: Development Stage P: Pilots Demonstrated Commercially N: Newly in Production; Introduced O: "Off the Shelf" Available

Technology	Energy Produced	Energy Conserved	Application	New Technology	Improved Older Technology	Adoption Issues	Zero Emissions	Incentive Eligible	Commercial Status	EERE Office
Advanced Process Control for Glass Production	NA	T, F	PC		X	A			RD&D	IT
Advanced Temperature Monitoring System Using Self-Validating Sensor Technology	NA	T, F	IPH		X	C, A			O	IT
Auto Glass Process Control	NA	T, F	PC		X	A			RD&D	IT
Development and Validation of a Coupled Combustion Space/Glass Bath Furnace Simulation	NA	T, F	PC		X	C, A			P	IT
Diagnostics and Modeling of High-Temperature Corrosion of Superstructure Refractories in Oxyfuel Glass Furnaces	NA	T, F	IPH		X	A			???	IT
Enabling Tool for Innovative Glass Applications	NA	T, E	PF		X	C, A			???	W&I
Enhanced Cutting and Finishing of Handglass Using a Carbon Dioxide Laser	NA	T, E	PF		X	C, A			P	IT
High-Luminosity, Low-NO_x Burner	NA	F	IPH		X	A			N	IT
Measurement and Control of Glass Feedstocks	NA	T, F	PC		X	A			RD&D	IT

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Technology	Energy Produced	Energy Conserved	Application	New Technology	Improved Older Technology	Adoption Issues	Zero Emissions	Incentive Eligible	Commercial Status	EERE Office
Monitoring and Control of Alkali Volatilization and Batch Carryover for Minimization of Particulate and Crown Corrosion	NA	T, F	IPH		X	A			RD&D	IT
Energy-Conserving Tool for Combustion-Dependent Industries	NA	T, F	IPH		X	A			P	W&I (NICE³)
Miniature, Inexpensive, Amperometric Oxygen Sensor	NA	T, F	IPH		X	A			P	W&I (I&I)
Fiber-Optic Sensor for Industrial Process Measurement and Control (Combustion)	NA	T, F	IPH		X	A				IT (SBIR)
Tunable Diode Laser Sensors for Monitoring and Control of Harsh (Combustion) Environments	NA	T, F	IPH		X	A				IT
Thermal Imaging Control of Furnaces and Combustors	NA	T, F	IPH		X	A				IT
In-Situ, Real-Time Measurement of Melt Constituents in the Aluminum, Glass, and Steel Industries	NA		PC		X	A				IT
Diagnostics and Control of Natural Gas-Fired Furnaces via Flame Image Analysis Using Machine Vision and Artificial Intelligence Techniques	NA	T, F	IPH	X		A			RD&D	IT

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Flat Plate Solar Thermal Collectors	T	T	IPH, HVAC		X	C, A, S	X	X	O	OST
Parabolic Trough Solar Concentrator	T, E	T, E	IPH, HVAC, EG	X		C, A, S	X	X	N	OST
Transpired Solar Collectors	T	T	HVAC	X		C, A, S	X	X	N	OST
Photovoltaic	E	E	EG	X		C, A, S	X	X	O	OST
Daylighting		E	L	X		C, A, S	X	X	N	OST
Combustion Turbine	E		EG, IPH		X	C, A, S			O	DERE
Microturbine	E		EG	X		C, A			N	DERE
Reciprocating Engine	E		EG, IPH		X	S			O	DERE
Biomass Energy	E, F	T, E, F	EG, IPH		X	C, A, S		X	O	OB
Landfill Gas Systems	E, F	T, E, F	EG, IPH		X	C, A, S		X	N	OB
Wind Power Systems	E	E	EG		X	C, A, S	X	X	O	OWH
Fuel Cells	E	E	EG	X		C, A, S	X		N	OWH
Oscillating Combustion	T	T	IPH	X		A			N	IT
Aluminum Roofing System	NA	E	HVAC	X		A			N	W&I

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Technology	Energy Produced	Energy Conserved	Application	New Technology	Improved Older Technology	Adoption Issues	Zero Emissions	Incentive Eligible	Commercial Status	EERE Office
PowerGuard®	E	T, E	EG, HVAC	X		C, A, S	X	X	N	W&I
WhiteCap®	NA	T	HVAC	X		A			N	W&I
RR-1 Insulating Screw Cap	NA	T	HVAC	X		A			N	W&I
High-Efficiency Direct-Contact Water Heater	T	T	IPH, HVAC		X	A			O	W&I
Solar Skylight Water Heater	T	T	HVAC	X		C, A, S	X	X	O	W&I
Radiant Heating Panels	T	E	HVAC	X		A			O	W&I
High-Efficiency Heat Pipe Dehumifidier	NA	E	IPH, HVAC	X		A			O	W&I
SOLARWALL®	T		HVAC	X		C, A, S	X	X	N	W&I
IceBear: Thermal Energy Storage for the Small Packaged Terminal Air-Conditioning Unit	NA	E	HVAC		X	A			N	W&I
Insulation Containment Apparatus (The Ultimate "R")	NA	T, E	HVAC	X		A			N	W&I
GibBAR-Wall™ System	NA	T, E	HVAC	X		A			N	W&I
A Dual-Fuel Conversion System for High-Output, Medium-Speed Diesel Engines	E	E	EG, IPH	X		A, S			N	W&I

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Technology	Energy Produced	Energy Conserved	Application	New Technology	Improved Older Technology	Adoption Issues	Zero Emissions	Incentive Eligible	Commercial Status	EERE Office
PowerRIM®	NA	E	L	X		A, S			N	W&I
Insulating Concrete Forms	NA	T, E	HVAC	X		A			N	OBT
Structural Insulated Panels	NA	T, E	HVAC	X		A			N	OBT
Cool Roofs	NA	T, E	HVAC	X	X	A			N	OBT
Desiccant Cooling and Dehumidification	NA	E	IPH, HVAC	X		A			N	OBT
Air-to-Air Heat Exchangers	NA	T, E	IPH, HVAC		X	A, S			O	OBT
Compact Fluorescent Lights	NA	E	L		X	C, A, S			N	OBT
Sulfur Lamps	NA	E	L	X		C, A, S			N	OBT
Light Emitting Diodes	NA	E	L	X		C, A			N	OBT
Electronic Ballasts	NA	E	L		X	A			O	OBT
Reflectors	NA	E	L		X	A, S			O	OBT
Fiber Optics	NA	E	L	X		C, A, S			N	OBT
Task Lighting	NA	E	L		X	A, S			I	OBT
Lighting Controls	NA	E	L		X	A			O	OBT

Notes on Adoption Issues:

"Cost" relates to longer simple payback periods, higher initial costs than conventional options, and performance risk perception
"Awareness" relates to lack of knowledge about technology and its benefits related to environment and performance, operating, and life-cycle costs
"Site" relates to physical plant issues for deploying technology at a factory complex and possible environmental regulation restrictions related to plant site

Section 1: Glass Industry Process and Process-Related Technologies

The Industrial Technologies Program (ITP) in the Office of Energy Efficiency and Renewable Energy (EERE) supports development of advanced energy-efficient process technologies for the glass manufacturing industry. In January 1996, working collaboratively with glass manufacturing companies, ITP published a technology research and development road map report entitled "Glass: 1996. A Clear Vision for a Bright Future." Four months later, a number of glass industry firms and organizations signed a compact with the Department of Energy on future cooperation between the industry and federal government on glass manufacturing technology development and deployment.

DOE and industry updated the glass industry road map in April 2002, and the revised strategy has four key elements.

- Production Efficiency – undertake research and development that will help the industry become more efficient, productive, and competitive.
- Energy Efficiency – identify and pursue technology that can reduce the gap between current process energy use and the theoretical minimum.
- Environmental Performance – achieve cleaner operations with lower environmental control costs and increased glass recycling.
- Innovative Uses – develop new applications for glass that reflect a higher technical content and positively impact the industry.

With an eye to the industry's future, these four elements have defined and guided DOE investments in glass industry research and development.

Besides technology development sponsored by ITP, financial support from the Department of Energy Inventions and Innovation Program to inventors and small businesses has developed a variety of innovations relevant for glass manufacturers that are now commercially available. Together, these two programs have contributed a number of energy-saving technology options for glass manufacturing companies, and others are in the pipeline. Since 1996, the technologies listed below have emerged from the DOE R&D program, and they are described in the following pages.

Process Technologies

- Advanced Process Control for Glass Production
- Advanced Temperature Monitoring System Using Self-validating Sensor Technology
- Auto Glass Process Control
- Development and Validation of a Coupled Combustion Space/Glass Bath Furnace Simulation
- Diagnostics and Modeling of High-Temperature Corrosion of Superstructure Refractories in Oxyfuel Glass Furnaces
- Enabling Tool for Innovative Glass Applications
- Enhanced Cutting and Finishing of Handglass Using a Carbon Dioxide Laser
- High-Luminosity, Low-NO_X Burner
- Measurement and Control of Glass Feedstocks
- Monitoring and Control of Alkali Volatilization and Batch Carryover for Minimization of Particulate and Crown Corrosion

Supporting Technologies

- Energy-Conserving Tool for Combustion-Dependent Industries
- Miniature, Inexpensive, Amperometric Oxygen Sensor
- Diagnostics and Control of Natural Gas-Fired Furnaces via Flame Image Analysis
- Thermal Imaging Control of High-Temperature Furnaces
- Tunable Diode Laser Sensor for Combustion Control
- Fiber-Optic Sensor for Industrial Process Measurement and Control
- In-situ, Real-time Measurement of Melt Constituents

Advanced Process Control for Glass Production

A significant fraction of the formed glass a television glass plant produces must currently be remelted due to poor product quality. Implementing improved quality-control measures can minimize waste production and save significant energy, reduce emissions, and decrease production costs. Pacific Northwest National Laboratory and Thomson Consumer Electronics developed and implemented an advanced process control system that will reduce waste and energy consumption by increasing the amount of high-quality product from the initial manufacturing step.

Description

The developed advanced process control system to decrease glass waste in manufacturing integrates the following four innovative technologies:

1. A physical model that relates process parameters (e.g., temperature, deformation, cooling rate) to final product quality;
2. A suite of novel, three-dimensional stress and temperature sensors for measuring process parameters;
3. A system for integrating and analyzing data from a variety of sensors; and
4. Cognitive control software for adjusting the process parameters to maintain product quality.

The system was initially developed to control forming of glass panels for televisions at the Ohio plant of Thomson Consumer Electronics.

Progress and Milestones

To develop the technology, PNNL and Thomson went through the following steps:

- Initiate model studies for television glass forming;
- Develop concepts for temperature and stress measurement;
- Develop finite element numerical models for TV panel glass forming;
- Experimentally verify concepts for temperature and stress measurements;
- Review historical data from Thomson plants;
- Apply glass models to television glass production;
- Demonstrate temperature and stress measurement diagnostics; and
- Demonstrate software algorithms for process control based on glass models and historical plant data.

Benefits

- Improved production efficiency and quality product yield based on significant reduction of glass waste.
- Decreased energy consumption by reducing the amount of remelting of poor-quality product.
- Made advances in modeling capability that will allow faster introduction of new products.

Applications
Upon successful demonstration of the process control methods, the new control system may be applied to other industry segments, including flat and container glass.

Project Partners
Pacific Northwest National Laboratory (Richland, Washington)

Thomson Consumers Electronics (Columbus, Ohio)

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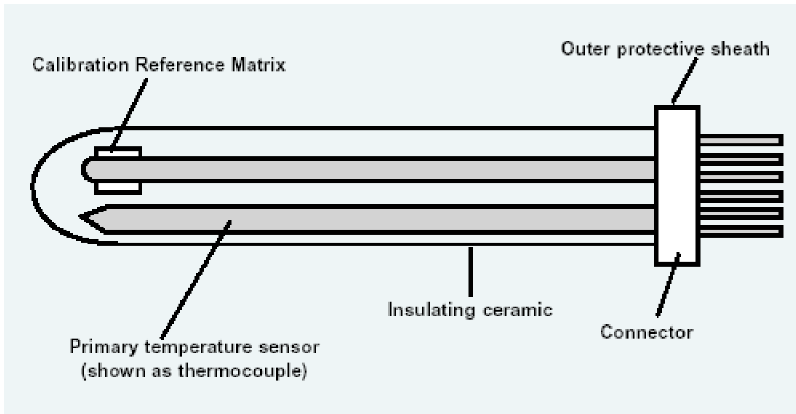
Advanced Temperature Monitoring System Using Self-Validating Sensor Technology

Self-validating sensor technology, developed by Accutru with support from the Industrial Technologies Program, is based on the ability to measure multiple, mutually exclusive thermoelectric properties of thermally sensitive materials contained in the tip of the sensor probe. Constructed like a thermocouple or RTD, the sensor probe is specially designed so that the thermal response of each element of the sensor can be monitored using independent combinations with multiple other elements. The signal conditioner/transmitter multiplexes these measurements and monitors the health of each individual thermo-element using at least two of its electrical properties.



Description

This concept makes it possible to continuously monitor and "validate" each of the measuring elements inside the sensor while it is in service so that no element can drift without detection. If an individual element begins to drift or de-calibrate for any reason, the system eliminates the data for that element while still providing an accurate traceable temperature in accord with National Institute of Science and Technology (NIST) standards with the remaining "healthy" elements. Using information about the number of "healthy" elements in the sensor, the transmitter then provides the operator or control system with sensor health status and notifies of impending loss of sensor validation before it occurs. Accurate and reliable temperatures are reported for the life of the sensor.

Progress and Milestones

As of 2000, 13 AccuTru sensor units were in operation. The system provides reliable temperature readings in the range of -200 °C to 1750 °C. It self-validates while in service for the life of the sensor, and warns the user on the onset of any decalibration. The capabilities facilitate predictive maintenance.

To summarize, the technology development and commercial applications have verified the following:

- A new concept of monitoring multiple independent measurements of the system temperature and individual element health;
- Continuous validation and reporting of the system temperature;
- Temperature reporting is traceable to a NIST standard for the life of the sensor;
- Capability to self-monitor and reports the health of the sensor; and
- Ability to give advanced warning of deterioration of any of the sensor elements.

This project has developed a new material approach that is leading to development of improved monitoring equipment.

Benefits

For glass manufacturing, the improved temperature sensing system has specific productivity gains. Demonstration has shown that it will reduce quality-control failures by 90% and increases the annual process yield by 10%. The result is better process optimization, improved fuel efficiency, enhanced safety, and extended equipment lifetimes.

Applications

Thermochemical processes that require accurate and repeatable temperature monitoring data. These would include glass melters and delivery systems, chemical reactors, heat treating, and gas turbines power systems

Project Partners

Developed by AccuTru International, Kingwood,Texas. AccuTru has also commercialized the technology and continues to market it.

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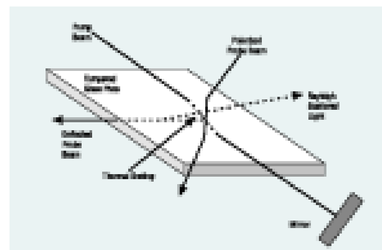
Auto Glass Process Control

Glass manufacturing accounts for the most energy consumption per vehicle in automotive production. It also produces significant amounts of product waste and atmospheric pollutants. To address these issues, Pacific Northwest National Laboratory and Visteon Glass Systems teamed to develop improved process control methods, including sensors and modeling, for manufacturing formed and tempered automotive glass that will increase process and energy efficiency, improve product quality and yield, and reduce production costs and waste.

Description



The project team effort to improve fabrication of tempered glass for the automotive industry had three main objectives:

1. Develop numerical simulation models to optimize the glass forming process and predict fabrication stresses and final shape;

2. Develop on-line, non-contact optical sensors to measure temperature and residual stress; and

3. Characterize the thermal and mechanical properties of glass in order to better understand stress distribution in automotive glass.

Progress and Milestones

- New method to measure in-plane stress was successfully demonstrated.
- Glass forming processes have been successfully modeled.
- New optical method for through-thickness temperature measurement successfully demonstrated.

Benefits

- Processing fewer unacceptable glass components will reduce harmful emissions and save an estimated 0.13 tons of waste per year per vehicle.

- Reduced process energy consumption (as much as 1.56 million Btu/year per vehicle in oil, gasoline, and electricity).

- Reduced production costs—enhanced process control will improve production efficiency and product yield and quality, reducing costs by about $80/unit.

Applications

While this new technology is being developed specifically for the automotive industry, it may be applied to other sectors of the glass industry in which glass must meet structural and strength criteria in stressing environments (e.g., architectural glass, container glass). Additionally, improved modeling capabilities will allow glass manufacturers from any sector to optimize the design of new products with fewer development iterations.

Project Partners
Pacific Northwest National Laboratory (Richland, Washington)

Visteon Glass Systems (Dearborn, Michigan)

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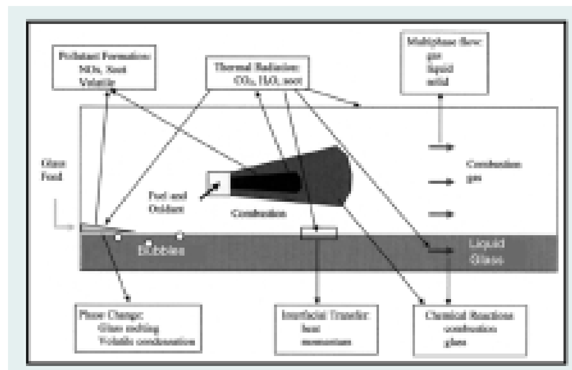
Development and Validation of a Coupled Combustion Space/ Glass Bath Furnace Simulation

Competitive and regulatory pressures are motivating glass manufacturers to seek new ways to improve productivity while reducing furnace energy use and emissions. The pursuit of these goals, however, often leads to conflicting requirements for the design and operation parameters of glass melting furnaces. To surmount these conflicts, a robust, validated, computational model of an entire glass melting furnace has been needed that would go further than existing three-dimensional computer models of the individual components of the melting system. Now such an innovative model has been developed that will directly couple the combustion space with the glass batch/melt through a rigorous spectral radiation model that computes radiant transfer throughout the whole furnace volume. This allows for spectral radiation from combustion species such as H_2O and CO_2 and radiation to and from the crown and glass melt, thus producing a more accurate model of the entire system. This accurate modeling tool will lead to optimization of existing melter operation, which in turn will improve production efficiency and quality while reducing operating costs and emissions.



Description

Argonne National Laboratory (ANL) developed the combustion space model with Purdue University assistance to ANL on development of the glass bath model.

The two models, together with a detailed glass batch model, were synthesized into one code by ANL and validated against existing industrial furnace measurements as well as data from a measurement program conducted on an operating furnace. The resulting three-dimensional, glass melting furnace simulation model provides a more accurate representation of the entire melting process by coupling the combustion space with the glass batch and the glass bath.

Progress and Milestones

The principal milestones of the two-part program have been achieved. A CFD-based combustion space model that incorporates a rigorous treatment of spectral radiation heat transfer throughout the whole furnace volume, to and from the crown, glass melt and glass batch, has been developed. The glass melt has been modeled with ANL's multiphase reacting flow code, directly incorporating a model of the glass batch. The combustion space and glass melt models have been coupled into an overall furnace model and used to develop a simulation of a Techneglas furnace. Initial measurements of key performance parameters in the furnace modeled have been made. An initial complete data set has been acquired and used to validate the furnace model. Electric boost and bubbler models were developed and incorporated into the furnace code.

Key technical objectives for the Part II program were to:

1. Incorporate glass chemistry models into the glass melt and to compute and track key solid, gas, and liquid species throughout the melt;
2. Activate the gaseous phase transport equations built into the glass melt model with source terms derived from the chemistry models to compute gaseous species production, bubble nucleation and growth, dissolution, and release from the glass melt surface (foaming);
3. Develop and incorporate chemistry and nucleation models of space;
4. Develop and incorporate glass quality indices into the simulation to facilitate optimization studies with regard to productivity, energy use, and emissions;
5. Develop and validate furnace simulations of three additional furnace types used in the industry; and
6. Conduct a workshop for the entire industry at the conclusion of the program where the code, furnace simulation and all data and information derived from the program will be made available to all.

At the conclusion of the project a user center will be established at Argonne National Laboratory that will be available to any organization in the glass industry interested in using the validated model to analyze its furnaces.

Benefits

- Optimization of melter operation and combustion process, yielding improved production efficiency and reduced costs and emissions.
- A modeling capability that can aid in problem solving and facilitate more rapid design and introduction of new products.
- Accessibility to modeling tools for manufacturers throughout the industry without the expense of maintaining in-house modeling capabilities.

Applications

Completion of this modeling project will give industry a validated, analytical tool that can be used to evaluate new furnace designs, evaluate furnace performance, develop optimal fuel-firing strategies, and devise methods to improve cost efficiency and environmental performance. Since the model was developed collaboratively with industry partners that already employ modeling capabilities, the development and validation of this coupled model will result in immediate application.

Project Partners

Argonne National Laboratory (Argonne, Illinois)

Libbey Glass Co. (Toledo, Ohio)

Mississippi State University (Mississippi State, Mississippi)

Osram Sylvania, Inc. (Exeter, New Hampshire)

Owens Corning (Granville, Ohio)

Purdue University (West Lafayette, Indiana)

Techneglas (Columbus, Ohio)

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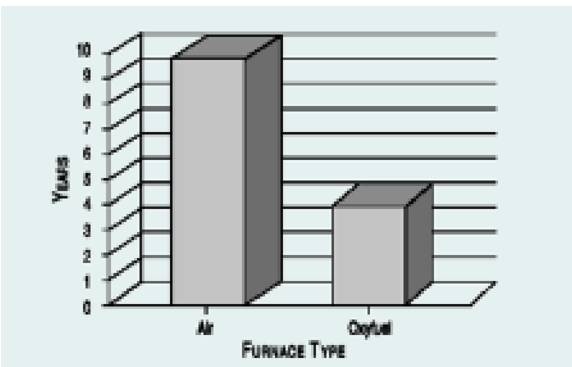
Diagnostics and Modeling of High-Temperature Corrosion of Superstructure Refractories in Oxyfuel Glass Furnaces

Combustion using pure oxygen is more fuel-efficient than combustion using ambient air, and "oxyfuel" firing is rapidly becoming an energy-efficient and environmentally sound alternative in the glass industry. However, higher temperatures and production of alkali vapors corrode refractories significantly faster in oxyfuel furnaces. For example, furnace crown life can be shortened by a factor of two to three. The glass industry will be more efficient if refractory is able to last longer so that oxyfuel burners can be employed more readily. A development step industry has needed is to characterize silica refractory corrosion processes in oxyfuel furnaces and use those characterizations to develop models that predict corrosion rates and define attributes of improved refractories.



Average furnace life based on corrosion of refractory structures

Description

With Department of Energy support, an industry team and Sandia National Laboratory collaborated to determine corrosion factors and develop mathematical models that can predict corrosion rates, identify operating conditions that minimize corrosion, and define the attributes of improved refractories for oxyfuel firing in glass furnaces. The researchers also developed optical techniques for monitoring gas-phase alkali concentrations in the melter head space. Improving the oxyfuel process by extending furnace life will increase the cost-effectiveness of the process and make conversion to this technology more appealing to the glass industry.

During the experimental and diagnostic development phase of the project, the researchers investigated the factors that contribute to corrosion rates, particularly gas-alkali species (e.g., sodium hydroxide, potassium hydroxide) that are the most damaging compounds that attack refractory. High concentrations of water vapor also produce increased amounts of damaging alkali. These higher concentrations of both alkali compounds and water vapor occur in oxyfuel furnaces as a result of the elimination of nitrogen from the input gases.

Progress and Milestones

The experimental and diagnostic development phase of the project started in 1999 and included the following activities:

- Characterization of new and used silica refractories;
- Conduct of iso-thermal corrosion simulations; and
- Measurement of alkali concentrations.

Benefits

Stronger capability to analyze performance of glass melting furnace refractory has led to development of improved refractory and operating conditions for glass manufacturing processes. These improvements have helped expand introduction of oxyfuel technology to glass melting furnaces, which has made them more energy efficient. Additional benefits include the following:

- Reduced production costs, since more corrosion-resistant refractories will lower the frequency of furnace rebuilds.
- More rapid industry adoption of cost-effective oxyfuel processes. Oxyfuel conversion can reduce NO_X emissions from a typical float glass plant from over 320 kg/hr to approximately 40 kg/hr.
- Improved product quality and energy savings by reducing defects. Defects resulting from corrosion byproducts dripping onto the glass surface currently cause a 2% reduction in yield, and total energy loss for the entire U.S. glass industry due to such defects is approximately 6 trillion Btu/yr.

Applications

The mathematical models created can be used by process designers, material engineers, and manufacturers in all segments of the glass industry, not only to optimize the oxyfuel process in existing furnaces and retrofits but also to design new ones.

Project Partners

Air Liquide (Countryside, Illinois)

Air Products and Chemicals, Inc. (Allentown, Pennsylvania)

BOC Gases (Murray Hill, New Jersey)

PPG Industries (Pittsburgh, Pennsylvania)

Praxair, Inc. (Tarrytown, New York)

Sandia National Laboratories (Livermore, California)

Visteon Glass Systems (Dearborn, Michigan)

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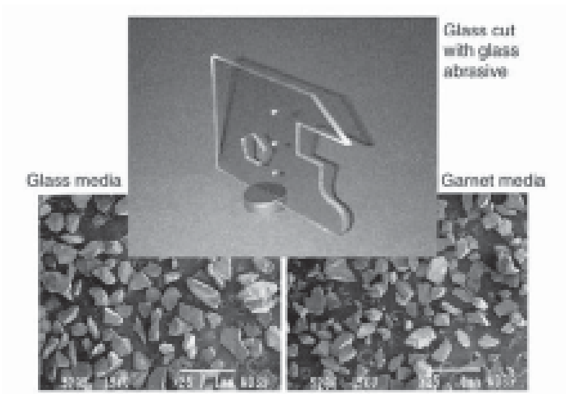
Enabling Tool for Innovative Glass Applications

Flat architectural and automotive glasses have traditionally been fabricated using scoring and flame breakout fracturing technologies. These processes have inherent cutting limitations because they are generally incapable of fabricating glass products with small radii, concave edges or pierced holes. These restrictions limit design and installation options for glass products.



Abrasive water jet cutting yields similar results to garnet abrasive media with less cost.

However, these restrictions can be mitigated with the use of an abrasive water jet (AWJ) cutting technique, which uses a stream of water carrying an abrasive material to erode the surface being cut. This technique allows the machining of hard and brittle materials, results in minimal heat build-up and deformation stresses, and allows greater flexibility in the machining of parts. Garnet abrasive media have proven to be the best performers in AWJ cutting, yet their expense has limited the use of AWJ cutting systems in the industrial sector to applications that are difficult to machine using conventional means.

A new technology employs waste glass as a new, low-cost abrasive media for AWJ cutting of glass and other materials. In addition, using glass to cut glass results in a homogenous waste stream that allows the glass particles to be reclaimed for use as a plastic filler. If the glass media is of sufficient quality, it could be recycled into the molten glass.

Description

The abrasive water jet cutting technique uses a stream of water with an entrained abrasive to cut materials. The most frequently used abrasives are silicates, particularly the garnet group. Glass is also a silicate, but in a non-crystalline form, eliminating concern for silicosis. Glass exhibits physical properties comparable to those of garnet, although its hardness is slightly less. Glass, when properly processed, has the same size and shape characteristics as garnet, and appears to be a technically equivalent, economically superior media for use in AWJ machining.

Reducing the cost of AWJ processing for glass could allow a wider variety of glass products to be produced, as AWJ can eliminate many existing design limitations for glass. In addition, when glass is used to cut glass, the resulting waste stream of fine, rounded glass particles can be reclaimed as a marketable by-product, which is usable as a filler with various polymers or recyclable back into glass production. Michigan Technological University is developing this new technology with the help of a grant funded by the Inventions and Innovation Program in the Department of Energy's Office of Industrial Technologies.

Progress and Milestones

- Develop a process to produce glass media through method testing and particle characterization.

- Test AWJ cutting with glass media to assess parameters and cutting performance.
- Characterize cutting and abrasive waste from AWJ cutting of plate glass.

- Evaluate glass particle waste as a filler in polymers used for injection molding.

Economics and Commercial Potential

The potential for cost savings and increased fabricating versatility for innovative glass applications with this tool is substantial. Garnet abrasives currently used in abrasive water jet cutting cost $0.34 to $0.42 per pound, while waste glass media is estimated to cost approximately $0.035 per pound, a savings factor of 10. With the cost of garnet representing approximately 35% of AWJ operating costs, there is substantial savings potential in the overall cost of operation.

Installing an AWJ system only requires modest modification of existing glass-cutting systems that use gantry-style robots. At the same time, the AWJ system eliminates the inherent thermal stresses and exhaust requirements of the flame breakout systems currently used in the manufacture of auto glass. Eliminating burners and makeup air requirements reduces fuel bills and CO_2 emissions. Meanwhile, the waste-glass abrasive makes the AWJ cutting system economical for use in production of a variety of intricately shaped and innovative new glass products. In addition, the abrasive water jet approach shows promise in its ability to machine other industrial materials, such as metals and ceramics.

Using waste glass as an abrasive media also strengthens the market for crushed glass. This strategy uses either mixed glass from recycling operations or a processed waste stream from within a glass facility.

Benefits

- Produces sharp-edged, angular particles from glass that are applicable as abrasive water jet media at approximately one-tenth the price of garnet.

- Improves glass manufacturing versatility and design flexibility by making abrasive water jet cutting more economical.

- Allows glass particle cutting-waste stream to be reclaimed for use as a plastic filler, reducing waste.

- Extends abrasive water jet technology with glass abrasive to cutting of a variety of materials, including aluminum, polymers, wood, and glass.

- Provides an outlet for mixed glass waste from recycling operations.

Applications

The new technology applies to the production of flat glass products. Use of waste glass makes abrasive water jet cutting economical for many types of glass design and installation, increasing versatility in glass fabrication. [In addition, the cutting-waste stream of fine, rounded glass particles becomes a marketable by-product, suitable for use as plastic filler.]

Glass as an abrasive can also be used with AWJ technology to cut a variety of industrial materials other than glass.

Project Partners

Inventions and Innovation Program, U.S. Department of Energy (Washington, District of Columbia)

Michigan Technological University (Houghton, Michigan)

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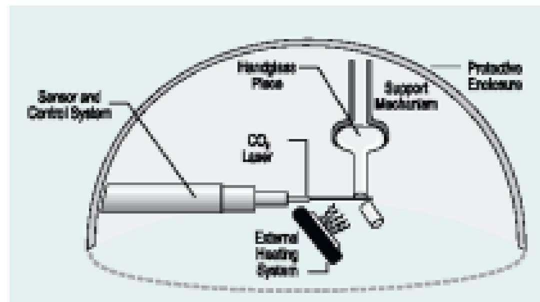
Enhanced Cutting and Finishing of Handglass Using a Carbon Dioxide Laser

Existing glass-cutting methods often result in considerable loss of glassware and require subsequent finishing of the edges, which is labor-intensive and can result in further product losses. Depending on the piece, glass properties, and worker skill level, losses can be as high as 80% in some product lines or 40% total scrap. The Federal Energy Technology Center, Fenton Art Glass, Pilgrim Glass, and West Virginia University worked together to develop laser-enhanced cutting and finishing methods that will dramatically decrease waste and improve productivity in the manufacture of handblown glass.



Laser-cutting the glass while still hot will create a fire-polished edge and minimize the need for further finishing.

Description

The partnership developed a bench-scale prototype system using a sensor-controlled, moderate-power, carbon dioxide laser to precision-cut blown glass and produce a finished edge. A major component of the work involved development of the operating parameters to make the system feasible for use in handglass factories.

The laser cuts the glass while it is still hot, producing a fire-polished edge that will minimize the need for further grinding or polishing. Throughout the process, the laser does not generate any photochemical by-products that could discolor the glass. Researchers also developed a heating system to keep the glass hot while the laser is in use. A sensor system controls the entire process; it turns the laser on, monitors the cutting, and disengages when the cutting is complete. The process is portable, uses readily available electrical power and cooling water, and was designed for use on a variety of glass products.

Progress and Milestones

The developers conducted extensive laboratory studies and a prototype design phase that included input from test partners to ensure compatibility with factory practices. The plan called for prototype system tests at several industry factories.

Prototype testing dictated a laser power of 1,000 watts to cut glass efficiently in a reasonable time interval. A robotic glass handling system was developed by Umbrella, Inc., for use in the factory prototype. The robot is easily programmed to handle any glassware and includes a vision system for piece recognition. The factory prototype system included the robot glass handler and computer control system from Umbrella, Inc., and a 1,300-watt CO_2 laser from Continental Laser Energy.

Benefits

- Improved product quality and reduced material costs as a result of minimizing waste and defects.

- Reduced energy use.

- Reduced hazards to workers since exposure to sharp edges and broken pieces will be minimized.

Applications

Handglass manufacturers of all sizes can use this enhanced technology. The system speed and efficiency offer increased throughput and reduced costs without an exorbitant investment—it is estimated that costs can be recouped in under two years. In addition, the improved production capability will encourage the timely introduction of new handglass products.

Project Partners

National Energy Technology Laboratory (Morgantown, West Virginia)

Fenton Art Glass Company (Sutton, West Virginia)

Pilgrim Glass Corporation (Ceredo, West Virginia)

West Virginia University (Morgantown, West Virginia)

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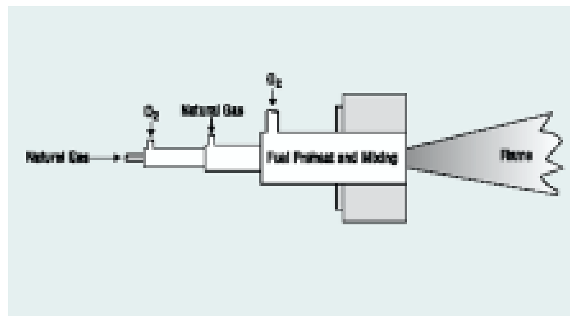
High-Luminosity, Low-NO_x Burner

While significant progress has been made in developing oxyfuel combustion systems, current technologies provide low-flame luminosity, which limits increases in production rates and thermal efficiency. These technologies also generate relatively high NO_x emissions in the presence of even small amounts of nitrogen (derived from air infiltration, N_2 in natural gas, oxygen, or feedstock). DOE is supporting development of an improved oxyfuel burner system for use in high-temperature glass furnaces that will increase thermal efficiency while reducing energy consumption and NO_x emissions.

Description



The Institute of Gas Technology is working with Combustion Tec and Owens Corning to develop a high-luminosity, low-NO_x oxygen/natural gas burner. This burner increases luminosity and radiant heat transfer by modifying the fuel prior to combustion and then forming and burning soot in the flame. Increasing heat transfer rates while decreasing flame temperatures results in increased furnace production rates and thermal efficiency.

The high-luminosity, low-NO_x burner combines a preheating zone with two combustion zones. First, a small fraction of the natural gas is burned. The products of this combustion are mixed with the main supply of natural gas, resulting in hydrocarbon soot precursors generated in an oxygen-free heating environment. The preheated natural gas then enters the first, fuel-rich combustion zone in which soot forms in the flame. The majority of the combustion, however, occurs in the second, fuel-lean combustion zone. The burning soot particles create a highly luminous flame that is more thermally efficient and cooler than a typical oxyfuel flame.

Progress and Milestones

Laboratory testing at 0.5 MM Btu/hr demonstrated an increase in heat transfer of more than 12% to an artificial load.

Demonstration testing at 2.25 MM Btu/hr confirmed a predicted increase in heat transfer and luminosity.

Commercial testing of the burner system on an oxyfuel fiberglass furnace was completed in 2000. In 2003, the development team is demonstrating it at a PPG plant with 50-50 financial support from a U.S. Department of Energy program, National Industrial Competitiveness through Energy, Environment, and Economics.

Benefits

- Increased thermal efficiency 20%.
- Extended furnace life due to lower flame and exit temperature.
- Reduced NO_x emissions (up to 50%).

- Reduced production costs—the burner provides cost-effective compliance with emissions regulations. Additionally, existing furnaces can be retrofitted without major modifications.

Applications
This novel burner can be used in all existing and new oxyfuel glass melters. Although the largest demand currently exists in the container, fiber, and specialty glass sectors of the glass industry, applications may also exist in other energy-intensive industries.

Project Partners
Combustion Tec, Inc. (Apopka, Florida)

Institute of Gas Technology (Des Plaines, Illinois)

Owens Corning (Granville, Ohio)

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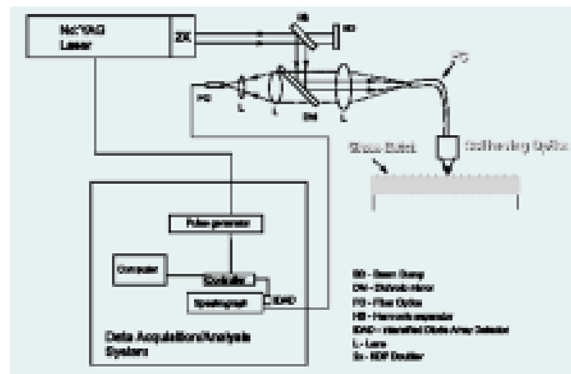
Measurement and Control of Glass Feedstocks

Laser-induced breakdown spectroscopy (LIBS) promises a new way for glass manufacturers to significantly increase productivity. By measuring the chemical makeup in raw materials and recycled glass cullet, LIBS can quickly detect contaminants and batch nonuniformity. By preventing the production of defective products, glass manufacturers can reduce production costs and improve glass quality.

LIBS provides high measurement speeds for the high throughput of small particles. The technology is capable of measuring both granular materials in the batch as well as larger materials, such as ceramic contaminants, that are often found in the cullet. These capabilities ensure that poor quality or non-uniform raw materials, contaminants, and batch mixtures do not enter the furnace. As a result of repeatable batch formulations entering the furnace, the technology will also allow for more optimal furnace parameters for particular mixtures.



By using the LIBS system and analyzing the data obtained, chemical makeup can be quickly determined.

Description

Two companies, a university, and a national laboratory are developing a LIBS probe to measure in real time and *in-situ* the chemical makeup of industrial glass processes and feedstocks. The LIBS device can immediately determine if a process or feedstock is off-spec and can be used in a feedback control loop to correct problems. Project partners have already experimentally verified LIBS probe feasibility and have been working on experiments with glass batch grains, recycled glass, and related contaminants.

The project partners are focusing on resolving problems associated with signal variability. In order to analyze many pieces of cullet per second, researchers must develop faster techniques. Artificial Neural Network (ANN) software is being tested to provide high-speed analysis of LIBS data. Other novel mathematical techniques will be employed to mitigate the effects of noise on LIBS signals.

Progress and Milestones

- DOE awarded the project funds in late 2000.

- During the first year of the project, researchers developed the capability to:
  - Measure elemental composition of glass batch;
  - Distinguish among different cullet colors at high speeds; and
  - Identify contaminants at high speeds.

- During the second and third year, the project team worked to:
  - Incorporate the ANN and remote sensing software into the LIBS Probe; and
  - Determine optimal settings of the LIBS instrument using flowing glass batch, cullet, and contaminants at the Fenton Glass facility.

Benefits

LIBS provides high measurement speeds for the high throughput of small particles. The technology is capable of measuring both granular materials in the batch as well as larger materials, such as ceramic contaminants, that are often found in the cullet. These capabilities ensure that poor-quality or non-uniform raw materials, contaminants, and batch mixtures do not enter the furnace. As a result of repeatable batch formulations entering the furnace, the technology will also allow for more optimal furnace parameters for particular mixtures.

The application of laser-induced breakdown spectroscopy to inspect glass processes and feedstocks is expected to yield the following benefits:

- Twenty percent reduction in product defects, saving the glass industry $220 to $440 million; and
- Energy savings of 260 to 520 billion Btu per year.

Applications

The LIBS device can be used to determine the chemical makeup of glass feedstock before it enters the melting furnace. The technology can improve product quality by determining batch integrity, sorting cullet by color, and detecting contaminants. The technology is expected to dramatically improve competitiveness in all sectors of the U.S. glass industry.

Project Partners

Energy Research Company (Staten Island, New York)

Fenton Art Glass Company (Williamstown, West Virginia)

Mississippi State University (Mississippi State, Mississippi)

Oak Ridge National Laboratory (Oak Ridge, Tennessee)

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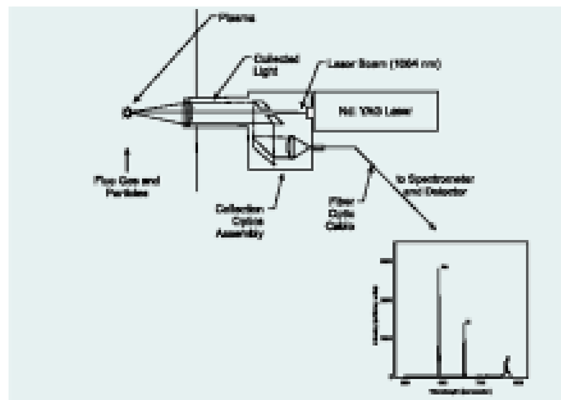
Monitoring and Control of Alkali Volatilization and Batch Carryover for Minimization of Particulate and Crown Corrosion

Laser-induced breakdown spectroscopy (LIBS) is a continuous monitoring technique that glass manufacturers can use to reduce particulate matter emissions and extend furnace life. By observing the correlation of metals concentrations with operating conditions over long periods of time, this new technique will identify batch properties and furnace conditions associated with batch carryover and alkali volatilization.

Because researchers expect the oxygen-to-fuel ratio to be among significant process variables, the measurements will allow additional efficiency improvements. The technology will provide glass manufacturers with real-time access to data directly related to particulate matter emissions and rates of crown refractory corrosion, information that is inaccessible using the monitoring and control equipment currently in place.



By taking measurements in the flue gas of glass melting furnaces, the LIBS instrument helps reduce particulate emissions and extend furnace life.

Description

Gallo Glass Company and Sandia National Laboratory have been collaboratively developing LIBS to reduce particulate matter emissions, increase furnace life, and improve furnace efficiency through simultaneous minimization of batch dust carryover, minimization of alkali volatilization, and optimization of oxygen-to-fuel ratio during glass melting and refining.

During the first two years of this three-year project, the project researchers collected data to determine the conditions having the greatest influence on high or low volatilization, batch carryover, combustion efficiency, and furnace efficiency. They also developed software for the control and acquisition of data from a broad-band LIBS instrument in the second year, and they are designing and building a prototype for tests.

Once the prototype has been tested, researchers will design a control strategy and system for minimizing alkali volatilization and batch carryover and maximizing furnace efficiency.

Progress and Milestones

DOE awarded funds to start the project in 2000. The first two years have been completed, and in 2003 the research team is to complete fabrication and testing of a prototype low-cost sodium and calcium monitor. The prototype will validate a strategy for minimizing volatilization and entrainment while maintaining high combustion and furnace efficiency.

Benefits

- Optimized use of raw materials.
- Improved combustion efficiency.

- Reduced particulate matter emissions.
- Improved furnace efficiency.
- Extended furnace life.
- Intelligent control.

Applications

This project addresses energy efficiency, emissions, and corrosion issues associated with soda lime glass melting. The technology used in this project will help minimize the costs of producing containers, flat glass, and other products.

Project Partners

Gallo Glass Company (Modesto, California)

Sandia National Laboratories (Livermore, California)

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Energy-Conserving Tool for Combustion-Dependent Industries

Current combustion-monitoring techniques are unable to effectively or efficiently monitor all combustion gases, including difficult-to-separate hydrocarbons such as formaldehyde. Typically, continuous emission monitoring (CEM) systems monitor a limited number of gases with an expensive collection of multiple single-gas analyzers. This unwieldy system requires a temperature-controlled room, shed, or trailer, and a substantial ongoing investment to maintain operation and calibration of the facility. Also, some compounds require physical transport back to a laboratory for analysis, a time- and cost-intensive process. A new technology is needed that greatly improves continuous emissions monitoring, while providing an on-line combustion-tuning tool. Such an innovation will increase operational efficiency, as well as reduce fuel requirements and subsequent air pollution.

Description

Advanced Fuel Research (AFR), in conjunction with On-Line Technologies, other industrial partners, the Connecticut Department of Environmental Protection (DEP), and with financial assistance from the Department of Energy's NICE³ Program, has demonstrated and is commercializing a new system that benefits combustion-dependent industries. The AFR multi-gas analyzer is portable, compact, low cost, and energy efficient. It allows real-time measurements of criteria emissions and hazardous air pollutants. The dramatic improvements in dependability and efficiency brought by AFR's analyzer should lower CEM operational energy costs by 70% and labor costs up to 83%.

The AFR system combines Fourier Transform Infrared spectroscopy (FT-IR), advanced mechanical/optical design, advanced electronics, and unique software for data analysis. Industry often monitors gas-phase streams by using electromagnetic radiation in the infrared spectrum, and FT-IR spectrometers are well known for providing advantages in measurement speed, sensitivity, and the ability to gauge multiple species simultaneously. However, FT-IR systems also have a reputation for not functioning well in industrial environments and for requiring an expert for successful operation. This project will prove otherwise for AFR's current state-of-the-art multi-gas analyzer.

The FT-IR base product to be demonstrated in this project offers the most advanced, high-speed, rugged, and portable FT-IR spectrometer available and is user friendly. Huge racks of single-gas analyzers will no longer be the norm for combustion process monitoring and CEM.

Advanced Fuel Research, Inc., is demonstrating this new technology with the assistance of Air Pollution Characterization and Control, the Connecticut DEP Bureau of Waste Management, Northeast Generation Service Company, On-Line Technologies, Pratt & Whitney, and the NICE³ Program in the Department of Energy's Office of Industrial Technologies.

Progress and Milestones

The project performed three simultaneous one-year demonstrations of a new, portable, low-cost, energy-efficient, multi-gas analyzer to prove it is a dependable state-of-the-art

CEM, as well as an on-line combustion-tuning tool that will save substantial energy and operational costs while reducing environmental emissions. The project plan developed the following:

- Instruments and sample transfer assemblies built and prepared for three installations during July 2000.
- Three multi-gas analyzers installed and operators trained during August 2000.
- Integrated data systems completed at three sites during September 2000.
- Complete long-term demonstrations and commercialization activities by September 2001.
- Conducted evaluations and continued commercialization activities through December 2001.
- Report commercialization activities annually for 10 years.

In late 2002, AFR sold two units of its multi-gas analyzer (MGA) developed for continuous emissions monitoring to Solar Turbines, in San Diego. Solar Turbines will use their MGA unit at a twin-turbine power station located at a university and compare its function to the existing CEM unit in place. The second MGA purchased by Solar Turbines will function as a mobile unit intended for periodic use at Solar Turbine's engine test cells in San Diego, their parent company Caterpillar in Illinois, and customer turbine sites in Alaska.

Benefits

- Provides on-line feedback for combustion tuning, resulting in lower energy use;
- Offers energy and capital savings of up to 70% compared to comparable monitoring devices;
- Measures criteria pollutants and hazardous air pollutants, such as formaldehyde and ammonia that are not traditionally monitored by continuous emissions monitoring;
- Reduces space requirements for measuring equipment by 94%; and
- Reduces maintenance and performance verification time, resulting in an 83% reduction in labor costs.

Applications

Industries that use boilers and combustion-turbine generation will benefit from the new CEM system. The chemicals, forest products, and petroleum industries show potential for process monitoring and cogeneration when used to reduce electrical costs and thermal supply. Engine manufacturers in the OIT Advanced Turbine Systems Program and utility power companies with boilers and/or turbines will also benefit.

Project Partners

Advanced Fuel Research, Inc. (East Hartford, Connecticut)

Air Pollution Characterization and Control, LTD. (Tolland, Connecticut)

Connecticut DEP Bureau of Waste Management (Hartford, Connecticut)

NICE^3 Program, U.S. Department of Energy (Washington, District of Columbia)

Northeast Generation Service Company (Rocky Hill, Connecticut)

On-Line Technologies, Inc. (East Hartford, Connecticut)

Pratt & Whitney (East Hartford, Connecticut)

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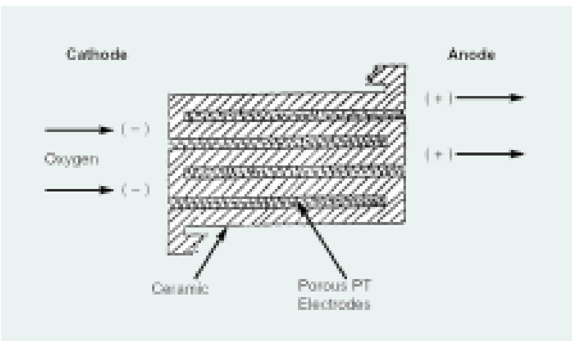
Miniature, Inexpensive, Amperometric Oxygen Sensor

Combustion systems are an integral part of industrial and commercial plants and processes. To maintain optimum fuel efficiency, analysis of boiler system combustion by-products is necessary. Measurement of the oxygen partial pressure derived from the boiler exhaust gas is achieved through the use of oxygen sensors, which have been available since the early 1970s. This analysis allows for the optimization of the air-to-fuel ratio and thus lowers energy consumption.



CeramPhysics' Amperometric Oxygen Sensor is a multilayer ceramic capacitor, which is ideal for inexpensive mass production and allows for miniaturization of the sensor.

However, current oxygen-sensor technology has limitations. Zirconia sensors, though accurate and reliable, are expensive. Their use is justified in large, industrial applications, but not in smaller-industrial or commercial applications. Also, some sensors available on the lower end of the price scale are unreliable.

In contrast, CeramPhysics' miniature, inexpensive, amperometric oxygen sensor was designed to overcome cost and reliability problems. With a target manufactured price of $50 each, including the measuring microprocessor, this new technology would be the least expensive oxygen sensor on the market.

Description

CeramPhysics has developed its amperometric oxygen sensor technology into a packaged system. The sensor uses a small, multilayer ceramic capacitor structure, consisting of anode and cathode electrodes inside a capacitor body. Oxygen diffusing from the cathode to the anode within the capacitor body produces an amperometric current that is directly related to the partial pressure of oxygen in the surrounding gas. In addition, a platinum track heater is incorporated in the capacitor body for an integrated sensor design.

Two different ceramics can be employed in the technology. A stabilized zirconia will be used in systems over 700 °C, while a stabilized bismuth oxide will be used in systems under 700 °C. Both sensor types are logarithmically linear in the combustion range, which is a distinct advantage over competing technology. In addition, the technology doesn't require a reference gas, and it consumes only about 2 watts during operation.

CeramPhysics Inc., developed this new technology with the help of a grant funded by the Department of Energy's Inventions and Innovation Program.

Progress And Milestones

- All work under the Inventions and Innovation grant has been completed.
- CeramPhysics has joined with a strong commercialization partner, Rosemount Analytical, an industry leader in oxygen analyzers and combustion-control systems.
- Protected by U.S. patent 4,462,891. A second patent is pending.

Economics and Commercial Potential

CeramPhysics' amperometric oxygen sensor offers potentially significant economic savings over conventional technology. The integrated sensor itself can be manufactured for less than $5. Packaged with a microprocessor, the manufactured system price is expected to be less than $50. In contrast, many existing systems in the industrial market cost more than $1,500. At this highly competitive price, the technology will be attractive not only to the full industrial market, but also to commercial and multi-unit and next generation residential markets, where oxygen sensors are not commonly used.

New, low-cost oxygen sensors would allow redundancy in a single measuring probe. When coupled with process control systems, this probe could monitor excess combustion oxygen while self-checking calibration, all at a cost comparable to single sensor probes currently available.

Benefits

- Potential to create cost savings of over $360 million per year, if the low-cost sensor increases combustion efficiency by 5% in the industrial, commercial, and residential markets.
- Inexpensive for mass production.
- Miniature size.
- Amperometric currents in the milliamp range.
- Sensitivity of oxygen partial pressure to 15 ppm.
- Good repeatability.
- Logarithmically linear signal response in the range of oxygen partial pressures found in combustion emissions.
- A response time faster than 40 ms.

Applications

CeramPhysics' amperometric oxygen sensor is primarily applicable to boiler systems. although the sensor can be used on large and small systems alike, it is particularly appropriate for industrial systems (furnaces, heaters, boilers), as well as commercial and multi-unit and next generation residential systems because of its highly competitive price. The technology is applicable to other combustion systems as well, like those in the automotive and bio-power industries.

Project Partners

CeramPhysics, Inc. (Westerville, Ohio)

Inventions and Innovation Program, U.S. Department of Energy (Washington, District of Columbia)

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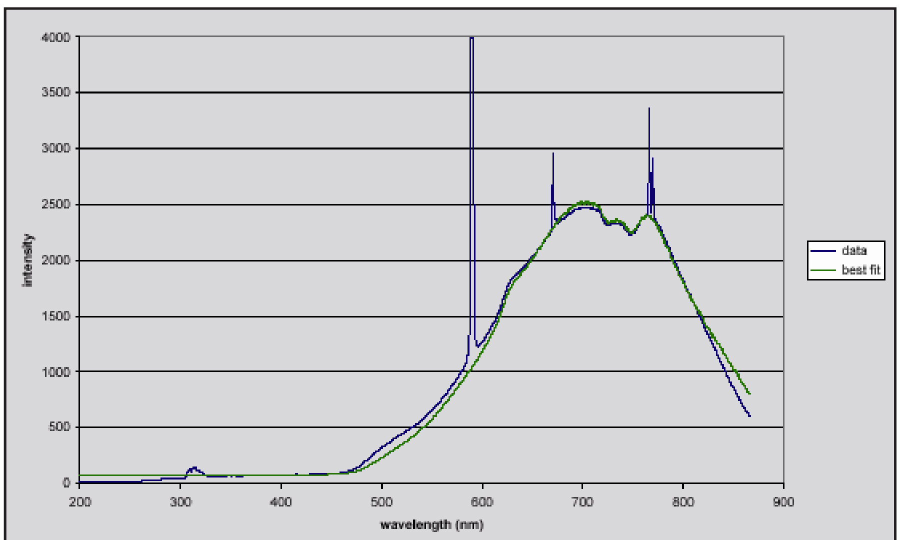
Diagnostics and Control of Natural Gas-Fired Furnaces via Flame Image Analysis

As compliance with emission regulations and higher natural gas prices turn more attention to control of combustion in glass industry furnaces, better techniques are needed to monitor and adjust the burner operating conditions. One new approach the Sensors and Automation function at the Department of Energy has supported would create an on-line monitoring system that employs computer artificial intelligence and advanced image analysis to process video images, which may be obtained using fiber optics. The pattern recognition techniques should be able to detect burner flame properties in real time and use the information to improve diagnostics and controls for natural gas-fired furnaces by "balancing" burners, i.e. realizing the same air/fuel ratio for each burner. In addition to improving efficiency, such precise flame temperature control can help significantly reduce NO_x emissions. Being able to see the temperature in various regions of the flame through continuous optical measurements will also help control glass product quality and reduce scrap losses.

Description

Goal: Formulate a method for extracting flame features from images that can be correlated with combustion parameters such as the air/fuel ratio, nitrogen oxide and carbon monoxide emissions, and flame temperature.



Spectral data and best-fit blackbody trace for VI region

The system being developed integrates technologies in order to detect burner malfunction, improve individual burner performance, and help operators balance oxidant (air or oxygen)/ fuel ratios among individual burners in multi-burner furnaces. Identifying and correcting fuel-rich burners should result in improved fuel efficiency. With all burners firing in unison, it is possible to lower the overall excess air, thus, gaining efficiencies.

The development project began with a feasibility study that collected flame data from fiber-optic detectors or spectrometers and flame images obtained by video cameras. A pilot-scale natural gas-fired furnace and a bench-scale, oxy-fuel glass furnace were used for these studies. After some preliminary data treatment, adaptive resonance theory neural networks were examined for recognition of flame patterns as a function of operational conditions. This information, along with virtual temperature sensing of the flame, was then used to develop control strategies. In Phase 2, a number of experiments were conducted using glass furnaces. The project team also upgraded the spectrometer design as well as assessed two AI tools (DT & NN) for pattern recognition. The final phase will further develop the system using data from a multi-burner commercial furnace and ready it for testing in a commercial-like setting.

Progress and Milestones

- This project was selected through the Sensors and Controls Program FY2000 solicitation and was initially funded in January 2000. Completion is scheduled for late 2003.

- The Phase I feasibility study was completed in 2001. The three majors tasks carried out were:

  1. Data/image acquisition using a combustor at Pennsylvania State University, oxy-fuel-fired experiments at University of Missouri – Rolla, and preliminary data processing.

  2. Flame image analysis with on-line digitization of input images and image processing to reduce the dimensionality of the data.

  3. Pattern recognition. A neural network was trained to use the image features to determine the conditions of the combustion process and to provide diagnostic information. To compare results, another neural network was used for unsupervised pattern recognition from the same image features.

- Phase II was completed in 2002. It included continued data analysis, experiments run under ramp-up conditions at various oxygen/fuel ratios, and combustion control and analysis experiments under step and ramp-up conditions.

- In Phase III, to be completed in 2003, the project will acquire data to analyze from an air/fuel pilot-scale furnace, design a graphical display, develop a prototype for the system, and package the software. The objectives to be achieved are to:

  1. Confirm system ability to generate reliable macro- and microscopic time varying flame image analysis;

  2. Establish the correlation between flame imagery and furnace control parameters for multi-burner operation;

  3. Verify system operation for both oxy-fuel and air-fuel multi-burner commercial glass furnaces; and

  4. Complete development of virtual temperature sensing capability.

Benefits

- Improved burner balancing would allow operation at lower excess air levels resulting in improved thermal efficiencies, reduced fuel consumption, and reduced NO_X emissions.

- For a large gas-fired boiler ($5.4x10^9$ BTU/hour), a 10% reduction in nitrogen oxide emissions could generate about $1 million per year in the form of NO_X emission reduction credits and save up to 5% of the fuel used.

- A small reduction in fuel consumption of 0.5% would result in fuel savings of more than $210,000 per year for an 80 MMBtu/hr gas-fired boiler at 2002 gas prices.

- Pro-active correction of damaging burner conditions will extend refractory life.

Applications

Applications for a smart on-line flame monitoring system include the following.

- Low-cost retrofit for implementing advanced process control for gas-fired furnaces used in the glass industry. Advanced glass melting process control would result in improved burner efficiency, reduced emissions, and improved product quality because of greater temperature uniformity.

- Real-time process control of multi-burner, natural gas-fired furnaces for melting scrap and recycled materials.

- Direct flame reading sensors for continuous control of NO_X and other pollutants in natural gas-fired furnaces for reheating steel for rolling operations, furnaces for forging, and furnaces for heat treating.

Project Partners

University of Missouri (Rolla and Columbia, Missouri)

Lehigh University (Bethlehem, Pennsylvania)

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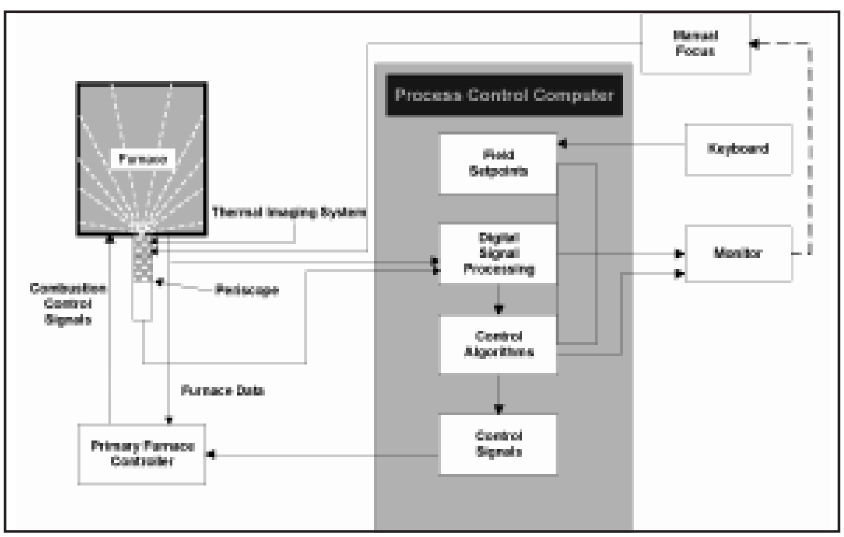
Thermal Imaging Control of High-Temperature Furnaces

Sensors and Automation, U.S. Department of Energy, provided support to a gas industry institute and university team to develop a control system for a type of high-temperature furnace that a number of industries employ. This technology measures furnace temperatures through near-infrared (IR) thermal imaging to provide information that can be used to improve combustion performance, and therefore fuel consumption and release of airborne emissions. The developed system can be used to generate feedback signals to minimize the difference between the actual measurements and set temperature values. Providing heat at desired locations inside the furnace has been shown to allow a decrease of at least 5% of total fuel usage, with a corresponding decrease in airborne CO, CO_2, and NO_X emissions. This system offers benefits to many energy-intensive industries including glass, steel, aluminum, chemical, and metal casting.

Description

Goal: Demonstrate and bring to commercial readiness a near-IR thermal imaging control system for high-temperature furnaces that is rugged, self-calibrating, easy to install, and reliably transparent to the furnace operator.

A dual-wavelength, near-IR thermal imaging control system creates a monitoring data stream from reading to reading to complement and assist the already existing furnace controller. The fine tuning can eliminate hot spots and mitigate instabilities. The system design calls for measuring flame intensity at 0.5 to 1 million pixels, using multiple IR wavelengths. A periscope probe is used to map the full field of combustion space during operation. The system required a reliable, low-cost dual-wave IR imaging system and software with enough speed to provide a temperature map and information in a format needed for furnace controls. The system also required some innovation to be able to generate thermal images of multiple surfaces at any angle relative to the camera lens over a temperature range from 500 to 2,000 °C.



Once the near-IR thermal imaging control system has proved itself in industrial demonstrations, the plan is for a project team member to market it to industries. Specific performance targets include a decrease of at least 5% in total fuel usage and a 30% reduction in NO_X production. Emissions of CO and CO_2 will automatically decrease 5% to match the decrease in energy input.

Success for the technoloy will depend on the ability to handle data and display it in near-real time (1-2 seconds) without requiring emissivity data. The data output was developed in a format that would be compatible with common furnace controls, and the user interface was made to accommodate multi-point set points.

Progress and Milestones

This project was selected through the Sensors and Controls Program FY1999 solicitation and funded in January 1999. The project began with a laboratory demonstration of the technical concept and associated technology. Then, the development team designed and fabricated an industrial demonstration unit that was used to test the thermal imaging and control technology.

Key tasks completed were:

- Definition of hardware for the thermal imaging system and capture of calibrated temperature maps at temperatures up to 1,200 °C in real time;

- Software written to control the thermal imaging hardware and to process intensity maps into temperature maps; and

- Processing of temperature map data into forms needed by control algorithms, and interface the input temperature profiles.

The development team worked in 2002 to:

- Finish fabrication of a control component and demonstrate thermal imaging and control on a bench-scale furnace; and

- Complete the design for a system installable in the field.

The field installation for testing a data analysis should be conducted in summer 2003 with plans to install a control unit on an air-gas and on an oxy-gas melter. New York State began providing funding support in 2003, and the planned final product will include a commercialization plan and complete marketing approach.

Benefits

- Fuel savings up to 5%
- Decrease NO_X emissions by up to 30%
- Decrease CO and CO_2 emissions by 5%
- Longer furnace life due to temperature control and elimination of hot spots
- Transparent control to the operators
- Adaptable to many types of furnaces as an add-on to existing controls
- A system that self-calibrates

Applications

The targeted industrial market for the thermal imaging control technology is high-temperature materials processing furnaces common to the glass, steel, aluminum, metal casting, and chemical industries. The technology is a less expensive option because it fine-tunes rather than replaces existing furnace control units, which lessens the financial risk.

Project Partners

Gas Technology Institute (Des Plaines, Illinois)

University of Illinois at Chicago (Chicago, Illinois)

Owens Brockway Glass Containers (Toledo, Ohio)

New York State Energy Research and Development Authority [NYSERDA] (Albany, NY)

U.S. Department of Energy Sensors and Automation Program (Washington, District of Columbia)

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Tunable Diode Laser Sensor for Combustion Control

In harsh industrial furnaces, control analysis of combustion processes conventionally relies on extractive sampling techniques that suffer from slow response times due to long sampling lines and inherent delays from the analyzers. In addition, maintenance costs are punishing because of probe degradation from plugging or corrosion and the need for frequent calibration. The Department of Energy and American Air Liquide addressed these issues through development of an *in-situ*, nonintrusive sensor that can capture data on internal furnace dynamics in real time. The ability to monitor a glass furnace at key process locations makes the sensor ideally suited for use with advanced combustion control techniques. With these features, low maintenance, and autonomous operation, such a sensor offers numerous economic benefits compared to conventional sensor technology.

Description

Goal: Develop and demonstrate a tunable laser sensor system for monitoring multiple gases and temperature in harsh combustion environments that can be used in conjunction with process control to improve energy efficiency, reduce pollutants, and optimize product quality.

700-kW Oxy-Fuel Pilot Furnace

The sensor development drew on technology from the telecommunication industry: near-infrared (IR) light from tunable diode lasers that are fiber-optic compatible, compact, and rugged. The system employs a 763-nm diode laser for oxygen measurements. To measure carbon monoxide and water vapor, the system uses a new diode laser technology with a tuning range of 10-nm to near 1,560-nm at microsecond rates. To make the sensor more cost-effective, the number of lasers was limited, and a balanced ratiometric circuitry was designed for laser noise reduction. The system works by directing near-IR light from the lasers through fiber optics to a collimator mounted at the process measurement point. This allows the lasers and associated electronics to be stationed far from the harsh process environment.

To collect data, the laser beam penetrates across the process and is received on the opposite side by a photo detector. The level of transmittance of the light propagating across the process is measured to provide the full line shape of the targeted absorbing species, which enables measurement of the absolute concentrations. Temperature measurements are made using the ratio of multiple absorption transitions of the same molecule.

Progress and Milestones

This project was selected through the Sensors and Controls Program FY2000 solicitation and was funded in May 2000. Completion is expected in 2003.

- Phase I Tasks Accomplished:

  1. Integration of multiple lasers, controllers, and data acquisition;
  2. Laboratory testing of simultaneous species monitoring of oxygen, carbon monoxide, water vapor, and temperature;
  3. Design of sensor process interface; and
  4. Pilot-scale testing for dynamic process conditions, effect of particulate and process radiation, and comparative measurement with conventional extractive sampling.

- Phase II Tasks:

  1. Development of an industrial prototype with robust, hardened optical integration components that have been optimized on the pilot-scale furnace;

  2. Planning and preparation for industrial site test;

  3. Hot-site testing at facilities operated by DuPont (sulfuric acid recovery), Johns Manville (glass fiber melter), and Charter Steel (reheat and electric arc furnace); and

  4. Selection of site for long-term demonstration with the sensor integrated into a control scheme to provide feedback control on the process fuel and oxide.

Before field testing, the sensor was thoroughly evaluated and optimized on a 700-kW oxy-fuel pilot furnace capable of 1,600 °C flue gas temperatures. In addition, the pilot furnace was equipped with a time-varying combustion technique for studying sensor response time and particulate injection to study the effect of monitoring hot, dirty flue gas. Since the objective of the sensor is to monitor near the process exhaust or in the process itself, fluctuations in the background radiation due to glowing particulate or reflected flame flicker can limit sensor accuracy. These issues were addressed to optimize the optical launch and collection system before testing at DuPont, Johns Manville, and Charter Steel. The combination of extensive pilot furnace testing and field testing on processes offering varying conditions laid a solid base for commercializing a truly versatile sensor for numerous industrial applications. Six patent applications have been submitted, and the DOE-supported project should end in 2003 with the technology developer positioned for follow-on commercialization activities.

Benefits

- Suitable for harsh environment temperatures (above 1,600 °C)
- Able to work in an environment with high particle densities
- Able to simultaneously monitor temperature and O_2, CO, and H_2O
- Fast response time of 1-10 Hz
- Calibration free
- Autonomous operation, integrated with processes control, and compact
- Near-IR diode lasers operate near room temperature
- Fiber optic compatible and simple electronic detection

Applications

- Monitoring and control of excess oxygen in glass melting tanks and reheat furnaces to reduce NO_X emissions.

- Monitoring of the atmosphere above glass baths to maintain a reducing or oxidizing level.

- Optimization of oxygen injection in electric arc furnaces for steel to maximize energy recovery from carbon monoxide off gas.

- Control of combustion in a steel reheat furnace to improve efficiency and maintain product quality by minimizing scaling and decarbonization.

Project Partners

American Air Liquide Chicago Research Center (Countryside, Illinois)

Physical Sciences, Inc. (Andover, Massachusetts)

Charter Steel (Saukville, Wisconsin)

DuPont (Deepwater, New Jersey)

Johns Manville (Littleton, Colorado)

U.S. Department of Energy Sensors and Automation Program (Washington, District of Columbia)

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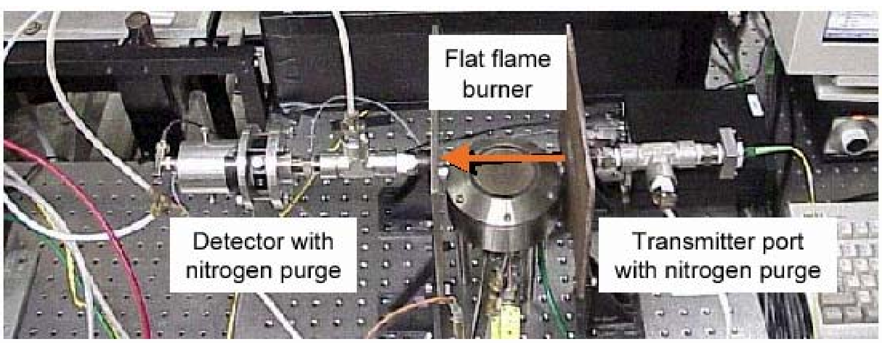
Fiber-Optic Sensor for Industrial Process Measurement and Control

Industry needs accurate, robust, and inexpensive sensors to monitor and better control combustion in industrial furnaces. Many existing sensors used to monitor industrial processes have limited value in applications involving highly corrosive gases at elevated temperature and/or pressure because they require extractive sampling systems that introduce variations in the temperature, pressure, and composition of the probed gases. In addition, sampling systems introduce a lag of 1 to 10 seconds in response times, require frequent servicing, and may be subject to unexpected failures because of their complexity. The U.S. Department of Energy has supported MetroLaser, Inc., to develop a gas and temperature sensor using near-infrared diode lasers to eliminate the need for sampling in glass furnaces. Such lasers are an attractive light source for sensing applications because they are rapidly tunable, small and lightweight, low-cost, efficient, and robust. They operate at near-ambient temperatures and produce narrow bandwidth radiation over a broad wavelength range.

Tunable diode laser absorption spectroscopy (TDLAS) affords a direct, quantitative measure of the gas species concentrations in the probed region of a process furnace. In addition, by monitoring two or more transitions, the sensor can determine the temperature along the optical path. This development project was designed to demonstrate the ability of diode laser-based fiber-optic sensors to measure temperature and species concentrations reliably and simultaneously, *in-situ* and in real time. The technology will enhance closed-loop control of a variety of industrial systems. These on-line sensors can be combined with process optimization control strategies to enable significant improvements in plant throughput, increase product quality, and reduce energy consumption and waste.



Description

Goal: Demonstrate the applicability of TDLAS to fabricate a real-time process control sensor for *in-situ* measurements of gas temperature and concentrations of CO, CO_2, and water vapor under conditions relevant to the glass, aluminum, chemical, and forestry industries.

The sensor was designed using fiber optics to combine multiple laser beams at different wavelengths into a single-probe beam. In an industrial process furnace the multi-wavelength probe beam can then be divided into several paths, allowing simultaneous measurements of temperature and species concentrations in multiple locations. By combining fiber-optic and diode-laser technology with laser-absorption spectroscopy, a compact, rugged, and economical sensor system was developed for species-specific measurements that are insensitive to interferences, particulate, and background emissions.

Progress and Milestones

This project was initiated through a FY1999 Small Business Innovation Research (SBIR) Phase I solicitation, and it was selected to advance to Phase II in June 2000. The scheduled completion date is in 2003.

Detailed spectral modeling for the target species at high temperatures and pressures was performed as a first step. Based on the information obtained, a breadboard TDLAS-based sensor for the measurements of gas temperature and water vapor, CO, and CO_2 concentrations was assembled at the Stanford University High Temperature Gasdynamics Laboratory (HTGL). Initial water vapor, CO, and CO_2 concentration measurements were conducted on a series of gas mixtures in a high-pressure, high-temperature sample cell. Gas temperature and water vapor concentration were measured using fixed- and scanned-wavelength absorption techniques. The diode-laser sensors were then tested with real-time measurements of temperature using water measurements in an HTGL laboratory combustion system that simulates industrial conditions.

A conceptual design of an *in-situ* sensor for harsh industrial environments was produced during Phase I. A TDLAS-based combustion control system is one end product and a flame temperature and H_2O mole fraction measurement for combustion chemical vapor deposition is another.

Key tasks that have been performed or are planned are:

- Conducted laboratory feasibility measurements to confirm hardware specifications needed for the conceptual design of the prototype;

- Discovered a new, single-laser wavelength strategy for the measurement of water vapor;

- Developed and demonstrated a breadboard diode laser-based chemical sensor system in laboratory conditions that replicated various industrial process environments;

- Identified Phase II demonstration test environment – 300-kW boiler simulator facility; and

- Advance the breadboard system to a rugged prototype design for testing and commercialization.

In the laboratory the system performed in a fixture flame zone where thermocouples had failed. The tests demonstrated data acquisition rates of 10 Hz, with potential for greater speed. Thus far, MetroLaser has identified new temperature measurement strategies and demonstrated temperature/mole fraction sensing in turbulent combustion. It was able to operate in multiple temperature sensing locations simultaneously, and it also performed the temperature and mole fraction measurements simultaneously. To complete the project, the team will demonstrate measurements of temperature and H_2O in a low-NO_X staged-fuel (SLN) combustor. Then the unit will have additional capability incorporated to detect CO_2, CO, and NO_X. The sensor has also been successfully applied to measurement of temperature and H_2O mole fraction in an industrial spray flame from a torch designed for combustion chemical vapor deposition of coatings.

The final project will be a lower-cost version of current modulation electronics for commercial use.

Applications

Real-time measurement and control of gas species concentrations in industrial process furnaces for the glass and other industries. For glass melting, the technology will enhance control by detecting more precisely in real time the species characteristics in the combustion zone above the melt and in the exhaust stream. For application of coatings, the TDLAS has been applied to and tested on an industrial alcohol/air spray flame torch designed for combustion deposition of coatings.

Project Partners

MetroLaser, Inc. (Irvine, California)

Stanford University High Temperature Gasdynamics Laboratory (Palo Alto, California)

Seika Corporation (Tokyo, Japan)

U.S. Department of Energy Small Business Innovative Research (SBIR) Program (Washington, District of Columbia)

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In-situ, Real-time Measurement of Melt Constituents

Based on previous Department of Energy support to develop laser-induced breakdown spectroscopy (LIBS) to measure chemical makeup in raw materials and recycled glass cullet, Energy Research Company has gained further Department of Energy support to develop and prove an additional application for the technology. It has configured its spectroscopic technology to measure, *in-situ* and in real time, the constituents of the melt in a process furnace. Currently, industry conducts elemental process analysis by periodically extracting a molten sample for laboratory analysis. This is expensive and time consuming, and it does not allow real-time control. By allowing *in-situ*, real-time measurement of melt constituents, this technology will:

- Improve product quality by reducing defects;
- Increase furnace cycle times, which could lead to continuous and semi-continuous operations;
- Increase furnace life by diagnosing the state of the furnace; and
- Provide necessary data to develop and validate computer modeling and simulation that will support more automation of furnace operations.

Description

Goal: Develop and test a LIBS-based probe in a laboratory crucible furnace to demonstrate *in-situ*, real-time measurement of melt constituents with an accuracy and minimum detection limit of 5% and 0.01%, respectively.

The LIBS technology employs a laser and a spectrometer to measure the constituents of a melted material in a process furnace. When a pulsed (5-10 ns duration) Nd:YAG laser at 532 nm is focused through a fiber-optic cable into a molten material sample, aluminum for example, it will generate high-temperature plasma consisting of excited neutral atoms, ions, and electrons. Any chemical compounds present in the sample will rapidly dissociate into their constituent elements. The laser-generated plasma is allowed to equilibrate several microseconds after the laser pulse, and the optical emissions from neutral and ionized atoms are collected and then dispersed by a spectrograph fitted with an intensified charge-coupled array detector. The line radiation signal amplitude can be calibrated quantitatively, thus providing the concentration of each element present. This development project succeeded in creating a probe that can withstand immersion in molten material and a system that does not require calibration.

Progress and Milestones

The LIBS sensor was selected through the Sensors and Controls Program FY1999 solicitation and was funded in January 1999. To date:

- Laboratory development work has been completed;
- Pilot-scale testing has been completed; and
- Tests are almost ready to be conducted at a commercially operating metals industry furnace.

In 2003, Energy Research Corporation was completing arrangements to test its LIBS system in an aluminum plant to measure metal melt. The company has completed its commercialization plan and has a license agreement for sale of the technology. Patents are pending, and a unit has been sold outside the United States.

Benefits

The *in-situ* LIBS sensor has the following benefits.

- Allows chemistry tolerances to be tightened
- Shortens the time needed to process information on molten material
- Increases production of higher quality product and reduces the amount of waste material
- Can lead to improved furnace designs and closer furnace control
- Improves the melt detection accuracy to 5% and the minimum detection limit to 0.01%.

Energy savings for glass industry molten glass processing have been estimated to be as high as 4.2 trillion Btu by 2010. The instrument may cost as little as $100,000 and will measure furnace temperature and melt constituents in real time. The technology could support a migration to continuous processing rather than batch processing in processes that melt material but must be closely controlled.

Applications

The main applications for the glass industry is for sensing the constituents in molten material. The technology is especially suitable to measure trace alkali metal content in electronic glasses as well as compositions that must meet close specifications for waste-vitrified and sealing glasses. The measurements can also detect refractory material in the melt to diagnose the condition of the furnace. The development of a survivable sensor probe will have application in several industries.

Project Partners

Energy Research Company (Staten Island, New York)

Oak Ridge National Laboratory (Oak Ridge, Tennessee)

U.S. Department of Energy Sensors and Automation Program (Washington, District of Columbia)

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Department of Energy BestPractices Assistance for Industry

BestPractices has organized its technical resources into these categories:

- Steam systems
- Pumping
- Electric motors
- Compressed air
- Industrial process heat

The BestPractices function within the Industrial Technologies Program in the Office of Energy Efficiency and Renewable Energy offers technical energy management tools and assistance to manufacturers to help them improve energy efficiency in the short term. BestPractices participants from industry that attend industrial efficiency awareness workshops are introduced to state-of-the-art efficiency concepts, DOE program resources, illustrative success stories, and also get to network with peers and solution providers. Industrial companies involved with DOE BestPractices are also exposed to the full technology portfolio of the Industrial Technologies Program.

Many companies are already realizing the benefits of applying a BestPractices approach. A large number get started by sending staff to a free DOE-sponsored workshop on the potential savings industry can realize by adopting BestPractices approaches. Others begin by applying for a cost-shared plant-wide energy assessment that is granted competitively to a small number of firms. (DOE will cover 50% of assessment costs up to $100,000). As a rule, companies have saved a minimum of $1 million annually from just one plant-wide assessment, with an average payback of less than 18 months.

DOE Technical Assistance For Industry

- Case studies and success stories document energy assessments that have successfully assisted manufacturers identify opportunities for immediate cost savings.
- Tip sheets that provide updated information on industrial equipment and systems to facilitate plant improvements.
- Industrial energy management experts for targeted, in-plant technical assistance.
- Tools and resources for measuring effectiveness of new technologies.
- Training sessions for plant personnel on software to identify and calculate savings for energy system improvements.

For small- and medium-sized plants, the Industrial Technologies Program supports 26 DOE Industrial Assessment Centers (IACs) that will send a team to a plant to conduct a free one-day plant energy assessment.

The DOE BestPractices staff maintains close links with expert trainers in the public and private sector. BestPractices offers as many as 40 training sessions annually on the various BestPractices areas to anyone in industry who wishes to attend. To date more than 10,000 people have trained with BestPractices in over 200 sessions across the country, and the value of training with the BestPractices team has been widely recognized by participating companies. Training gives plant personnel the knowledge and resources needed to save energy on multiple levels within a plant. Training can also be a valuable team-building exercise that helps workers take responsibility for finding ways to improve energy efficiency and increase productivity. BestPractices can do in-plant training to address specific areas in a production facility.

Critical to the success of BestPractices are DOE Allied Partners—manufacturers, industrial service and equipment providers, industry trade associations, and utilities. These organizations and companies have agreed to work with industry or implement proven technologies along with the best energy management practices in their own operations. Their participation strengthens the Industrial Technologies Program strategy of focusing attention on energy-intensive industries, and in return they get easier access to DOE resources.

DOE BestPractices Energy Management Training Covers:

- Steam system assessment
- Pump systems
- Motor systems
- Thermal systems insulation
- Compressed air
- Industrial process heat

Those who engage with DOE's BestPractices function will enter a network comprised of professional representatives from manufacturing companies, energy service firms, universities, national labs, trade associations, government, and non-profit advocacy organizations. This network and contacts are valuable for:

- Finding partners or participants in new technology research, development, and deployment;
- Collaborating in the planning and presentation of industry forums;
- Extending communication through sales and distribution networks to a wider industry audience; and
- Engaging "champions" or first movers who can influence their industry peers.

Get Involved

A number of avenues exist to participate in BestPractices activities.

- Visit the DOE and linked websites for current news and information
- Download or order free documents and software tools
- Attend a BestPractices Awareness Workshop
- Attend one of many trainings
- Respond to solicitations for plant-wide assessments and technology validation and verification classes
- Become an Allied Partner
- Sign up to host a Showcase Demonstration
- Subscribe to the *Energy Matters* newsletter

For more information, contact the OIT Clearinghouse at (800) 862-2086, or visit the website www.oit.doe.gov/bestpractices.

Environmental Connection

The BestPractices energy management team helps companies cut energy use and significantly lower emissions, which in turn leads to a cleaner environment for everyone. Several companies have used DOE resources to save energy and cut emissions. . .

Georgia Pacific
Reduced annual emissions of CO_2 by 34.6 million pounds, SO_2 by 3,460 pounds, and NO_x by 26,000 pounds.

Rohm & Haas, Inc.
Reduced CO_2 emissions by 51,350 tons annually.

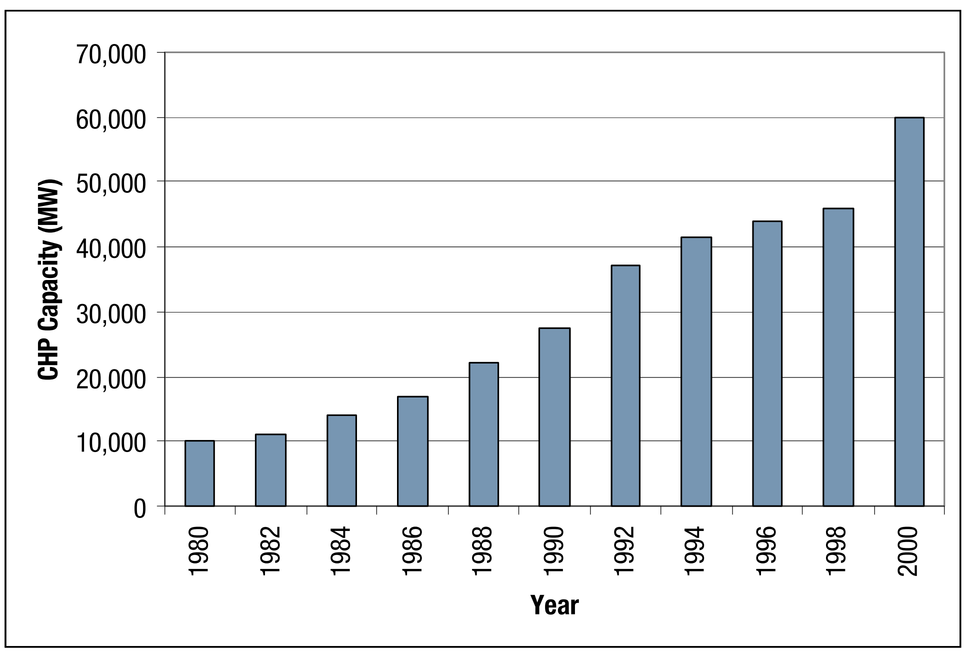
AMCAST
Reduced CO_2 emissions by 11 million pounds annually.

These improvements benefit not only the companies but also their communities and the nation.

Section 2: On-Site Electrictricity and Thermal Energy Generation Technologies

The Department of Energy Office of Energy Efficiency and Renewable Energy (EERE) supports research, development, and demonstration of distributed energy resources to improve industrial energy efficiency, reduce emissions, and expand the use of renewable energy alternatives. Distributed energy refers to self-generation of electricity or use of renewable energy technologies to make electricity or thermal energy. The Department of Energy's mission statement on distributed generation is to:

- Improve the efficiency, environmental outputs, and reliability of generation, delivery and end-use systems;
- Support high-risk research through public/private partnerships and performance-based programs;
- Measure performance on efficiency, cost, and emissions;
- Reduce dependence on foreign oil through fuel flexibility; and
- Increase security and reliability of energy supply.



U.S. growth of combined heat and power capacity

The EERE goal is to facilitate installation of 27,000 megawatts of combined heat and power (CHP) systems using distributed energy resources by 2010. To reach the goal, the technology development program is working on microturbines, reciprocating engines, fuel cells, materials, and energy storage technologies. It supports integration of combined heat and power systems with absorption chillers and desiccant systems and is working to facilitate end user integration through demand management, and sensor and control technologies. To assist self-generators, the program has also focused attention on the integration of electricity and natural gas supply where it pertains to load management, power electronics, and protection of sensitive loads. With regard to connection issues with the electric grid, the program support has given attention to load management, power parks, microgrids, energy storage, uninterruptible power supply, and potential of DC electric grids. The program has also developed assessment tools for end users.

This section of the Guidebook describes distributed energy technologies that would be applicable to a glass manufacturing plant. The most common are fossil energy-fired electric power generators that can entirely or partially eliminate the need for a manufacturing facility to purchase utility energy.

On-site electric power systems using natural gas, coal, or petroleum generally require a significant investment and trained staff to operate the equipment safely and reliably. But the benefits of matching a power system to specific plant requirements can provide significant advantages in energy costs, reliability, power quality, and lessening of environmental impacts. Table 2-1 lists the main characteristics of advanced fossil-fuel power technologies. Renewable energy technologies can also be used to generate electricity or thermal energy on-site. Biomass energy systems are similar to fossil fuel systems, except the technology must take into account varying heat content of the fuels used. Solar, wind, geothermal, and hydroelectric are other renewable energy technology options. These systems require a larger up-front capital investment that is offset by the "free" delivered energy over the life of the system.

Fossil fuels, petroleum and natural gas, plus electricity—which is mainly produced by coal and natural gas, are the dominate sources of energy for glass industry processes. Based on 1994 and 1998 industry data DOE collected, energy used for just glass processing in plants nationwide broke out as follows:

	1994 MECS Data*	1998 MECS Report+
Electricity	14.9%	19.6%
Residual Fuel Oil	1.6%	1.6%
Natural Gas	74.7%	78.8%

* 1994 data as reported by Energetics, Inc., April 2002. "Energy and Environmental Profile of the U.S. Glass Industry." U.S. Department of Energy Office of Industrial Technologies.
+ 1998 data from DOE Energy Information Administration's Manufacturing Energy Consumption Survey (MECS).

Note: 1998 MECS data indicated that distillate and diesel fuel and LPG were each under 0.5 trillion Btu out of 203 trillion for glass industry total energy consumption.

The data above show that purchased electricity has grown more important as a source of processing energy for glass manufacturing, a trend that should create more interest in and opportunity for on-site energy production and combined heat and power systems. The key is to assess the net present value of distributed energy resources and factor in the environmental benefits such systems afford.

Assessment

Installing on-site fossil-fuel power generation can provide significant cost benefits for a glass manufacturing facility by supplying a significant portion of plant-wide demand for electricity and thermal energy. Assessing the potential of on-site power generation starts with a com-

Table 2-1: Characteristics of Fossil-Fuel Power Technologies						
	Diesel Engine	Natural Gas Engine	Steam Turbine	Gas Turbine	Micro-Turbine	Fuel Cells
Electric Efficiency (LHV)	30-50%	25-45%	30-42%	25-40% (simple) 40-60% (combined)	20-30%	40-70%
Size (MW)	0.05-5	0.05-5	Any	3-200	0.025-0.25	0.2-2
Footprint (sq.ft./kW)	0.22	0.22-0.31	<0.1	0.02-0.61	0.15-1.5	0.6-4
CHP installed cost ($/kW)	800-1,500	800-1,500	800-1,000	700-900	500-1,300	>3,000
O&M cost ($/kWh)	0.005-0.008	0.007-0.015	0.004	0.002-0.008	0.002-0.01	0.003-0.015
Availability	90-95%	92-97%	Near 100%	90-98%	90-98%	>95%
Hours between overhauls	25,000-30,000	24,000-60,000	>50,000	30,000-50,000	5,000-40,000	10,000-40,000
Start-up time	10 sec	10 sec	1 hr - 1 day	10 min - 1 hr	60 sec	3 hrs - 2 days
Fuel Pressure (psi)	<5	1-45	n/a	120-500 (may require compressor)	40-100 (may require compressor)	0.5-45
Fuels	Diesel, residual oil	Natural gas, biogas, propane	all	Natural gas, biogas, propane, distillate oil	Natural gas, biogas, propane, distillate oil	Hydrogen, natural gas, propane
Noise	Moderate fo High (requires building enclosure)	Moderate to High (requires building enclosure)	Moderate to High (requires building enclosure)	Moderate (enclosure supplied in unit)	Moderate (enclosure supplied in unit)	Low (no enclosure required)
NOx emissions (lbs/MW-hr)	3-33	2.2-28	1.8	0.3-4	0.4-2.2	<0.02
Uses for heat recovery	Hot water, LP steam, district heating	Hot water, LP steam, district heating	LP-HP steam, district heating	Direct heat, hot water, LP-HP steam, district heating	Direct heat, hot water, LP steam	Hot water, LP-HP steam
CHP output (Btu/kWh)	3,400	1,000-5,000	n/a	3,400-12,000	4,000-15,000	500-3,700
Usable temp for CHP (degrees F)	180-900	300-500	n/a	500-1,100	400-650	140-700

Source of data: Onsite Sycom, *Review of CHP Technologies*, October 1999 parison of the cost to self-generate electrical power relative to the cost of purchased electricity. The costs to be estimated include the initial capital investment (installed cost), operation and maintenance (O&M), and fuel supply. Making a projection of inflation or deflation of utility power prices and the price of the fuel used to generate energy on-site is a critical step. While self-generation is not always a preferred option, there is a great deal of unrealized cost-comsaving potential for it in the industrial sector. The technology descriptions found on the following pages will provide an overview of this potential for each type of technology in the Guidebook.

If a manufacturing plant has significant demand for electricity, on-site generation of electrical power may be an economical alternative to purchasing power from the utility. The electricity generated can be used to provide for a plant's entire electrical load or supplement it. When deciding on the merits of on-site generation, it is critically important for the glass manufacturer to have thorough data on electric and thermal energy use.

A factor to consider is prevailing local area demand and pricing for utility generated electricity that could make potential sales of excess capacity profitable. Under the Federal Public Utility Regulatory Policies Act, utilities are required to negotiate a contract with cogenerators and independent energy producers that will allow excess energy produced to be sold back to the utility at the utility company's avoided cost for generation. If a glass company begins to consider an on-site generation system, it may stimulate a utility to negotiate a more favorable rate structure for the plant to forego the project.

An economic consideration that may make on-site generation more attractive is the ability to operate on a variety of fuels (i.e., oil, natural gas, coal, or biomass). Switching fuels can help smooth energy price volatility if long term fuel contracts are balanced with short term supply options. The glass industry relies very little on petroleum products at this time, so the potential is less, but dramatic increases in natural gas prices since 2001 could stimulate more attention to fuel diversity.

Table 2-2: Power Reliability Costs

Industry	Average Cost of Downtime
Cellular Communications	$41,000 per hour[1]
Telephone Ticket Sales	$72,000 per hour[2]
Airline Reservations	$90,000 per hour[2]
Credit Card Operations	$2,580,000 per hour[2]
Brokerage Operations	$6,480,000 per hour[2]

[1] Teleconnect Magazine
[2] Contingency Planning Research, 1996

Self-generation is also a form of insurance because critical plant loads can be supplied to avoid production disruptions from power outages. On-site power systems in the current market have been engineered with very good reliability. If these systems are maintained according to the manufacturers maintenance schedules, they can operate for thousands of continuous hours. Table 2-2 shows the average cost of downtime losses incurred by several industries that are highly dependent on electrical power.

A plant's power quality may depend on its location, electrical equipment used in the facility, and the power factor correcting equipment utilized by the utility. If a plant is having problems with power quality, self generation may provide a solution. Good power quality is critical in manufacturing plants utilizing digital control systems.

On-site generators may also be configured to produce thermal energy to meet in-plant thermal loads. Combining electricity production with captured waste heat raises overall energy efficiency and lowers costs in the long term. A combined heat and power system can provide the entire thermal energy supply for a plant, or supplement existing furnaces and boilers through a staging configuration. For example, a smaller furnace can be used to supply heat at its maximum design efficiency in a base load configuration and the thermal output of the CHP system can be used to meet peak demand.

The relative size of electric versus thermal loads is a key consideration. For most of the glass industry, the thermal load dominates, and it generally will make most economic sense to generate electricity and use the waste heat from the electric power generation as a by-product to supplement the larger thermal energy system. The waste heat can produce hot water, steam, or process heat. Because the available heat is recovered and used, the electricity generation can attain higher efficiencies, for example, a smaller on-site generator could achieve an overall energy efficiency of 35 to 45%. In comparison, a small 2-megawatt condensing steam turbine to make electricity would be about 24% efficient.

The advanced fossil-fuel power technologies in this section are engineered to perform at higher system efficiencies. Per unit output, these will require less fuel combustion; therefore, they produce fewer emissions. In the case of CHP systems, the system efficiencies increase to the range of 35 to 50%. These systems can also be fitted with pollution control devices that will reduce various pollution emissions. Specific details are discussed in the description of each system. With regard to emissions, solar thermal and photovoltaic systems and wind energy technologies do not generate on-site emissions and their application can generate pollution offsets.

The other significant assessment issues that should be considered include regulatory costs and costs imposed by the incumbent utility. Some of these are discussed in Appendix A.

The following pages cover the technologies listed below.

Fossil-Fuel Technologies

- Combustion Turbines
- Microturbines
- Fuel Cells
- Reciprocating Engines

Renewable Technologies

Electricity

- Biomass
- Photovoltaic Systems
- Wind Power Systems

Thermal Energy

- Flat Plate Solar Thermal Systems
- Parabolic Trough Solar Thermal Systems
- Solar Thermal Transpired Collectors

Combustion Turbines

Combustion turbines (CT) are stationary prime movers that can be used to supply on-site electrical power and thermal energy for industrial plants. Typical sizes range from 3 MW to 200 MW and have full load efficiencies ranging from 30 to 42%. CT systems can be configured with various ancillary components to meet specified performance and emission abatement requirements, and can also be configured for dual-fuel flexibility—the capability to switch between a supply of oil and natural gas.

CT technology has been adopted from aircraft turbojet engines and operates on the same Brayton cycle principles. The working fluid, ambient air, is drawn into the engine's compressor to be pressurized. After exiting the compressor stage, it moves through the engine to the combustion chamber where fuel is added and ignited. The combustion process adds energy to the air, significantly increasing its velocity and temperature as it moves towards the back of the engine. Most of the energy in the working fluid is extracted by a multi-stage turbine system used to drive a series of power shafts. These rotating shafts are used to drive the compressor stages and to spin a generator to produce electricity. Excess thermal energy not converted to mechanical power can be recovered for process heat, hot water, or steam production.

Gas Combustion Turbines

1992
29% efficiency
Double digit ppm NO_x emissions
$600/kW equipment cost

2001
38% efficiency
Single digit ppm NO_x emissions
$400/kW equipment Cost

2010
<5 ppm NO_x
Cost competitive with the market

Source: U.S. DOE Distributed Energy Resources Program Presentation, March 2003

Depending on a facility's energy demands, integrating CT systems may be an economically beneficial option when considering the costs associated with meeting a facility's electrical and thermal loads.

Economics

Capital costs range between $700 - $900 per kilowatt installed and typically depend on system capacity and specified ancillary equipment. Economic incentives offered by federal and state programs can reduce these costs. See Appendix B for more information.

Operation and maintenance (O&M) costs are in the range of 0.4 - 0.5 cents per kWh for typical maintenance schedules but will vary for specific operating conditions. Routine maintenance is required about every 5,000 - 8,000 hours[1] and major overhauls every 30,000 - 50,000 hours[2].

Environmental

The two main types of emission controls used with combustion turbine systems are water/steam injection and selective catalytic reduction. Water/steam injection systems introduce water or steam into the turbine combustion stage. The water or steam lowers the combustion temperature, which reduces the formation of thermal NO_x. Typical NO_x levels without control systems are between 75 - 200 parts per million (ppm). Water and steam can reduce NO_x emissions to 42 ppm and 25 ppm, respectively. Maintaining water purity is a key concern due to corrosion issues with contaminants.

The second system used to control emissions from combustion turbines is selective catalytic reduction (SCR). An SCR system injects ammonia into the exhaust in the presence of a catalyst and can reduce NO_x emissions by 80 to 90%. These systems can be used alone, or in conjunction with the water/steam injection systems mentioned above. If SCR is employed, the exhaust temperature must be lowered to a specified level before the ammonia can be added. Storage of the ammonia may also be a concern because it is a hazardous material.

Market

Combustion turbines are widely available in the commercial market. Until recently they ranged from 500 kW to 25 MW of capacity; however, microturbines are now entering the market (see the following section on microturbines). Aircraft-derived combustion turbines have been growing in demand as a choice for power generation in utility and industrial applications. During the 1980s combustion turbines generated 20% of total U.S. electric power. As a result of CT technology improvements in reliability and performance during the last 20 years, this technology now accounts for 40% of new electric capacity additions. The Department of Energy's Energy Information Administration (EIA) cites forecasts that predict that CTs may expand to supply 80% of all new capacity additions in the U.S.

Technology Outlook

Current research is focusing on several areas to increase system efficiency and emission characteristics of combustion turbines. These include development of ceramic turbine vanes that will allow the engines to operate at higher temperatures. Greater engine efficiency will increase shaft power and lower emissions. It will also produce more waste heat that can be used for raising steam and making hot water.

Other areas of research include powder metal alloy materials for turbine disks, high-pressure airfoils using advanced film cooling concepts to optimize cooling air, and catalysts to improve system durability.

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[1] http://www.energy.ca.gov/distgen/equipment/combustion_turbines/combustion_turbines.html
[2] Onsite Sycom, *Review of CHP Technologies*, October, 1999

Microturbines

Microturbines are small-scale combustion turbines designed to produce on-site electricity and recover thermal energy that may be utilized for process heat applications. A typical microturbine unit is about 4 feet long and 5 to 6 feet high and weighs about 180 pounds. Additional equipment (such as the motor control system, gas compressor, and battery) increase the space requirement to about 12 cubic feet and increases the total weight to about 300 pounds. Power output ranges from 25 kW to 500 kW, and the energy conversion efficiency ranges from 20 to 30%. Multiple units can be combined if additional capacity is required. Microturbines are fuel flexible, and can operate on natural gas, bio or landfill gas, hydrogen, propane, and diesel oil.

A microturbine operates with the same principles as a conventional combustion turbine, pressurized combustion exhaust gases rotate a turbine. But in contrast to the axial flow design of a conventional combustion turbine in which the working fluid moves perpendicular to the plane of the turbine, a microturbine incorporates a radial design derived from automotive turbochargers and auxiliary power units (APUs) used in aircraft in which the flow of the working fluid is parallel to the plane of the turbine. Due to the smaller size of the various components, the turbine in a microturbine rotates at very high speed: 90,000 to 120,000 RPM. Some designs have incorporated air bearings to eliminate the need for a lubricating system.

Economics

Capital costs currently run about $4,500 - $6,000 per kW. These may be reduced by federal and state incentives for microturbine applications. See Appendix B for more information.

Maintenance and operating costs run about 0.5 - 1.0 cents per kWh with biannual scheduled maintenance. See Appendix A for possible additional costs.

The competitiveness of microturbines relative to other technologies or purchases of electricity depends on the extent these penetrate the marketplace. Manufacturing economies of scale due to significant increases in demand should make these products competitive with traditional alternatives (i.e., conventional power generation technologies and purchased electricity).

Environmental

For their size, microturbines operate efficiently and can be configured with several pollution control devices. NO_x emissions range anywhere between 9 and 50 parts per million (ppm). These levels are attained typically without post-combustion pollution abatement equipment.

Market

Microturbines for stationary generation have only recently been introduced commercially. Although there have been some commercial installations, microturbine production is still low in volume. Most installations are associated with a field testing program or part of a larger scale demonstration project. For example, Capstone Turbine Corporation (http://www.microturbine.com) has delivered 1,700 units to a variety of customers since October 2001.

Technology Outlook

Research is being conducted to increase the efficiency and reliability of microturbines. One development project includes the use of multiple-stage turbines that will allow for lower rotational speeds. Another project is investigating ceramic turbine blades able to withstand higher operating temperatures and increase efficiency. A third research project is exploring modifications, such as catalytic combustors, that will allow microturbines to operate on biogas fuels.

Microturbine Technical Progress

2000
17 - 30% efficiency
Double digit ppm NO_x emissions
$900 - $1,200/kW cost

2007
40% efficiency
Single digit ppm NO_x emissions
Cost competitive with the market

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Fuel Cells

Fuel cells operate quietly, convert energy efficiently, and do not generate air pollution normally associated with fossil fuel combustion. A self-contained system, they use an electro-chemical process similar to a battery to produce electrical power. But unlike batteries that are recharged using electricity, fuel cells combine oxygen and hydrogen without combustion to produce clean, utility-quality electricity. These systems utilize a modular design and are "stacked" to provide the required capacity. Along with electric power, these units also produce high-quality waste heat that may be utilized to supplement energy for heating water or raising steam. Technology development is underway for fuel cells from as small as 40 kW up to a megawatt or more in generating capacity.

Fuel cells convert natural gas, propane, and in some cases gas derived from coal to electricity. Rather than combusting fuel, these systems utilize a processor or internal catalyst to convert the hydrocarbon into a hydrogen-rich gas. Then another process oxidizes this gas and breaks it down into protons and electrons where movement within an electrolyte produces an electrical current. The output produced from these systems is direct current (DC) power, which can be easily converted by an inverter to alternating current (AC).

Economics

The phosphoric acid fuel cell (PAFC) was the first fuel cell to be commercialized as a distributed generation product. United Technology Corporation manufactures a 200-kW phosphoric acid fuel cell at a cost of approximately $4,000/kW. Some have projected that PAFC manufacturing costs are between $3,000 and $3,500/kW. Balance of system and installation would raise the overnight capital cost to $1 million for a 200-kW system. This amounts to approximately $5,000 per kW of capacity. The Department of Energy has helped promote fuel cells through a $1,000/kW subsidy.

For the various types of fuel cells under development, projected capital costs range widely, from $3,500 - $10,000 per kW. Projections suggest the factory production cost could drop to between $1,000 and $1,500 per kW. Currently available fuel cells produce electricity for about five to seven times the cost per kilowatt-hour of a natural gas-fired turbine.

Operation and maintenance (O&M) costs are estimated to be between 0.5 - 1.0 cents per kWh. The fuel supply system and the reformer require annual maintenance. The cell stacks should not require maintenance until the end of their service life. Typical schedule maintenance requires major overhauls between 10,000 and 40,000 operating hours. More firm O&M data will be forthcoming as fuel cell technology begins to gain a commercial foothold.

Although the capital and delivered energy costs are high, some applications can justify costly measures to offset the risk of production losses due to loss of power. This is particularly true for electronic controls for production systems. These costs may be reduced by federal and state incentives for fuel cell applications. See Appendix B for more information.

Table 2-3: Characteristics of Current Fuel Cells

	Alkaline (AFC)	Proton Exchange Membrane (PEM)	Phosphoric Acid (PAFC)	Molten Carbonate (MCFC)	Solid Oxide (SOFC)
Electrolyte	Alkaline lye	Perfluorated sulphonated polymer	Stabilized phosphoric acid	Molten carbonate solution	Ceramic solid electrolyte
Typical Unit Sizes (kW)	<<100	0.1-500	5-200 (plants up to 5,000)	800-2000 (plants up to 100,000)	2.5-100,000
Electric Efficiency	Up to 70%	Up to 50%	40-45%	50-57%	45-50%
Installed Cost ($/kW)		4,000	3,000-3,500	800-2,000	1,300-2,000
Commercial Availability	Not for CHP	R&D	Yes	R&D	R&D
Power Density lbs/kW ft^3/kW		8-10 ~0.2	~25 0.4	~60 ~1	~40 ~1
Heat Rejection (Btu/kWhr)		1,640 @ 0.8V	1,880 @ 0.74V	850 @ 0.8V	1,780 @ 0.6V
Electric/Thermal Energy		~1	~1	Up to 1.5	Up to 1.5
Oxidation Media	Oxygen	Oxygen from Air	Oxygen from Air	Oxygen from Air	Oxygen from Air
Cooling Medium		Water	Boiling Water	Excess Air	Excess Air
Fuel	H_2	H_2 and reformed H_2	H_2 reformed from natural gas	H_2 and CO reformed from natural gas or coal gas	H_2 and CO reformed from natural gas or coal gas
Operating Temp (°F)	160-210	120-210	320-410	1,250	1,500-1,800
Operating Pressure (psig)		14.7-74	14.7-118	14.7-44	14.7->150
Applications	Space and military (today)	Stationary power (1997-2000) Bus, railroad, automotive propulsion (2000-2010)	Stationary power (1998) Railroad propulsion (1999)	Stationary power (2000->2005)	Stationary power and railroad propulsion (1998->2005)

Source of data: Onsite Sycom, *Review of CHP Technologies,* October, 1999

Environmental

Fuel cells produce nominal emissions. Combined hydrogen and oxygen generate waste water. The conversion efficiency of the source fuel to electricity ranges between 35 and 50%. If waste heat is used in a co-generation configuration, the energy conversion efficiency can exceed 80% for the entire system.

Market

Many small proton exchange membrane (PEM) cells have been installed for very small terrestrial applications. For stationary power applications, the PAFC is the only type that has entered the commercial market, starting around 1993. The other types remain in various development stages [See Table 2-3]; however, some appear nearly ready to compete with PAFC technology for commercial installations. Typical applications stack modular cells in units with a capacity between 100 - 200 kW. Since its introduction, the PAFC has been installed in over 165 applications. In short, the current market is niche based and located where a premium is placed on reliability and where electricity prices are high and natural gas prices are low.

Technology Outlook

NASA has long used fuel cells to power the space shuttles. Another driver for the technology is the automotive market, and combined with potential demand for stationary power systems and use of hydrogen as fuel, fuel cell development will continue to be supported with government funds. There are five main types of fuel cells being developed for commercial applications. Characteristics and estimated commercialization time frames are summarized in Table 2-3. Phosphoric acid technology has demonstrated 35 to 40% conversion efficiencies and good reliability. Efforts are continuing to improve the PAFC fuel cells as mentioned in the Market section and four additional technologies are currently being developed. These are the Alkaline Fuel Cell (AFC), Proton Exchange Membrane Fuel Cell (PEMFC), Molten Carbonate Fuel Cell (MCFC), and the Solid Oxide Fuel Cell (SOFC).

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Reciprocating Engines

Reciprocating engines for stationary power applications are like internal combustion engines used in the automotive industry. Power is derived from the combustion that occurs in a circular cylinder, which moves a bank of pistons up and down. The movement of the pistons rotates a crankshaft converting thermal energy to mechanical energy. Reciprocating engines are typically based on the Otto and Diesel cycles. The Otto cycle uses a spark plug to ignite the air/fuel mixture in the cylinder and the diesel cycle achieves combustion from the compression of the air/fuel mixture. Natural gas versions of the internal combustion engine currently have thermal efficiencies between 37 and 40%, and advanced future technology could cut NO_X emissions to as little as 1 gram per bhp-hr. These engines are commercially available, with demonstrated abilities to support local power grid requirements, combined heat and power applications, fuel supplies from wellhead to landfill gasses, and most recently prime power to meet regional power shortages.

Reciprocating engines have a large share of the market for distributed generation. They are suitable for a variety of applications due to their small size, low unit costs, and useful thermal output. They are easy to start, and have a proven reliability record. They also have good load-following characteristics. Possible applications for reciprocating engines in power generation include continuous or prime power generation, peak shaving, back-up power, premium power, remote power, standby power, and mechanical drive use. When properly treated, the engines can run on fuel generated by waste treatment (methane) and other biofuels.

Economics

Capital costs run about \$300 - \$800 per kW.

Maintenance and operating costs run about 0.5 - 1.5 cents per kWh with biannual scheduled maintenance. Engines utilizing natural gas typically have lower maintenance costs than engines operating on diesel fuel. See Appendix A: Regulatory Barriers to Implementation for possible additional costs.

Environmental

There are two different types of controls used to reduce Otto-cycle engines emissions: combustion controls to create lean burn (higher stoichiometric air-to-fuel mixture) conditions and catalytic emissions treatment for rich burn (lower stoichiometric air-to-fuel mixture) conditions. To produce lean burn conditions, excess air (50-100% above stoichiometric requirements) is supplied to lower the combustion temperatures to produce a lean air-fuel mixture. The lower combustion temperatures limit the creation of NO_X and CO. Typical NO_X emissions for a lean-burn engine on a horsepower basis is 0.5 - 2.0 grams per hour. These levels can be further reduced to less than 0.15 grams per hour with post-combustion selective catalytic reduction (SCR), which injects ammonia into the exhaust.

Emissions from rich-burn engines can be reduced with the use of catalytic converters treating the exhaust. The catalysts control the emissions by converting the NO_x to N_2 with a reducing agent and CO to CO_2 with an oxidizing agent. These controls can reduce the typical rich-burn NO_x levels from 9 grams per hour on a horsepower basis to 0.15 grams per hour.

Diesel engines require leaner air-fuel mixtures; therefore, they operate at relatively lower temperatures than Otto cycle engines. SCR systems are sometimes utilized to reduce diesel emissions, but catalytic controls have a nominal effect. The growing environmental concern with diesels is the release of particulate matter. Filters and traps are available to capture particulate matter before it is released into the air.

Market

Reciprocating engines are widely available in the commercial market. They come in a variety of sizes and can be configured to suit various applications from a few kilowatts to 7 MW.

Technology Outlook

The EERE program is focused on raising conversion efficiency of advanced natural gas reciprocating engines to 50% by 2010, a 30% increase compared to current average efficiency. The NO_x target is 0.1g/hp-hr, a 95% decrease from today's NO_x emissions rate, to be achieved with no deterioration of other criteria or HAPS emission. The program also aims to adapt the technology to be dual fuel capable. The target for busbar energy costs, including operating and maintenance costs, is 10% less than current state-of-the-art engine systems while meeting new projected environmental requirements.

Reciprocating Engines Technical Progress

2000
25 - 40% efficiency
2 - 3 grams/kWh NO_x emissions
$300 - $400/kW cost

2007
50% efficiency
<0.15 grams/kWh NO_x emissions
Advanced natural gas
Cost competitive with the market

Diesel engine technology is also being improved due to stricter emission regulations. Federal regulations will require use of low-sulfur diesel fuel; this is already required for oil combustors in certain EPA designated non-attainment areas. EPA has also recently regulated emissions from stationary diesels used for such purposes as agricultural pumping. Advanced emission control technologies are being funded by state and industry/government programs. These include such ideas as microwave destruction of particulate. SCR systems are also being developed to further reduce emissions in diesel engines.

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Biomass Systems

Bioenergy resources account for three percent of commercial primary energy supply in the United States. The term "biomass" means any plant-derived organic matter available on a renewable basis, and it includes dedicated energy crops and trees, agricultural food and feed crops, agricultural crop wastes and residues, wood wastes and residues, aquatic plants, animal wastes, municipal wastes, and other waste materials. Bioenergy technologies use these renewable biomass resources to produce energy-related products including, solid, liquid, and gaseous fuels; chemicals; and other materials. Handling technologies, collection logistics, and infrastructure are important aspects of the biomass resource supply chain. Biopower technologies are proven electricity-generation options in the United States, with 10 gigawatts of installed capacity. Almost all of this capacity uses mature direct-combustion technology. Future efficiency improvements will include co-firing of biomass in existing coal-fired boilers and the introduction of high-efficiency gasification combined-cycle systems, fuel cell systems, and modular systems.

The most common application of biomass fuels is waste wood burning in the pulp and paper industry, which primarily uses direct-fired boiler technology to generate heat and steam for mill operations. Glass companies would not find biomass combustion attractive unless a ready source of combustible waste were available near to a glass plant. In such circumstances, a cogeneration or strictly electricity-generating distributed energy plant might become attractive if self-generation were cost competitive with utility rates.

Another technical option the Department of Energy has investigated is "co-firing," which refers to introducing biomass in high-efficiency coal-fired boilers as a supplementary energy source. Co-firing has been evaluated for a variety of boiler technologies including pulverized coal, cyclone, fluidized bed, and spreader stokers. For utilities and power generating companies with coal-fired capacity, co-firing with biomass may represent one of the least-cost renewable energy options. The glass industry uses little if any coal; consequently, co-firing of biomass with coal in direct-combustion systems is not likely to be of interest unless natural gas prices stay at recent highs. Glass companies could consider using gaseous fuels derived from biomass as an option in the future.

A variety of fuels can be made from biomass resources, including the liquid fuels ethanol, methanol, biodiesel, Fischer-Tropsch diesel, and gaseous fuels such as hydrogen and methane. If natural gas supplies tighten and prices climb, gasification of biomass or biomass mixed with coal to produce a low Btu gas could become a competitive option for glass companies to fire their gas furnaces. Low Btu gas systems have significantly lower NO_X and sulfur dioxide emissions. Tars and oils from the gasification process would furnish supplemental fuel, and elemental sulfur recovered from a coal/biomass fuel process could be sold to increase the economic return on such a system. Industrial coal gasification systems have been installed in the past to gasify coal when natural gas was curtailed and certain industries needed gaseous fuel to operate existing single-fuel process heat systems and boilers.

Economics

Direct-fired biomass steam cycle plants to make electricity typically use single-pass steam turbines, and they have tended to be large plants, 50 megwatts and more. In the past decade, efficiencies and more complex design features, characteristic previously of only large scale steam turbine generators (> 200 MW), have been transferred to smaller capacity units. Current biomass designs include reheat and regenerative steam cycles as well as supercritical steam turbines. The two common boiler configurations used for steam generation with biomass are stationary- and traveling-grate combustors (stokers) and atmospheric fluid-bed combustors.

The EERE biomass energy program has provided a cost estimate for a 50 megawatt direct-fire biomass power plant using a 1997 base case—the McNeil Station located in Burlington, Vermont—with wood heating values about 10 MJ/kg on a wet basis and 20 MJ/kg on a dry basis. The estimated cost for base case plant for fuel handling, boiler, turbine generator, and balance of plant was $1,197/kW in 1997. Engineering, fees, building structures, cost of funds, permitting, etc., could bring the implementation capital cost up to $1,965/kW for such a unit. Looking ahead, DOE projected the cost for the power portion of such a system to fall to $922/kW of capacity by 2005 with total implementation capital cost falling to $1,510/kW. The estimated cost of electricity from such a system would be 5.5 cents per kilowatt-hour from the baseline 1997 system, and 4.74 cents/kWh in 2005.

	1997 Basecase	2005
Capacity MW	50	50
Capacity Factor	80%	80%
Efficiency	23.0%	27.7%
Net Heat Rate kJ/kWh	15,280	13,200
Annual Energy Delivery GWh/yr	350	700
Estimated cost/kWh	5.5 cents	4.74 cents

Gasification: The Department of Energy Clean Coal Program has supported development of high-pressure pure oxygen two-stage gasifiers for coal utility applications and a number have been built as demonstrations. Costs have remained too high for the utility industry to adopt this option. The EERE biomass program has supported work with smaller scale systems suitable for industrial applications; however, no foothold has been achieved in the market. Several studies have indicated that there should be little difference in cost of electricity (COE) between systems employing high and low pressure gasification technology. Some technical proposals for modernized, simpler atmospheric gasifiers that would combine industrial waste or biomass with coal indicate that the delivered cost of low Btu gas could range between $3.50 and $5.50 per million Btu. These systems would likely be employed first to produce boiler or furnace fuel. Older versions of such technology were deployed in the 1970s, but no recent industrial scale systems have been built in the U.S. to convert biomass resources to gas. Again, if natural gas prices rise over the next few years, biomass systems may become an alternative source of furnace and boiler gas for glass manufacturing plants.

Environmental

There are a number of benefits of using biomass-derived electricity. Biomass is lower in sulfur than most U.S. coals. Higher sulfur biomass fuels have levels less than the regulated limit set by the New Source Performance Standards (NSPS) for coal that have prevailed since the late

1990s. Controlled NO_X levels from biomass plants will also be less than the NSPS standards. Biomass is a renewable resource that consumes carbon dioxide during its growing cycle. Therefore, it should contribute no net carbon dioxide to the atmosphere when biomass is produced and consumed on a sustainable basis as part of a dedicated feedstock supply/energy production system. Transportation costs and emissions for biomass per unit of energy generated is higher than coal because of the higher heat content of coal per pound. There are limits to the distance that biomass can be transported economically for energy production.

Market Status

Direct-fired wood combustion systems have an established market presence in the U.S. In the mid-1990s, there were approximately 7 GW of grid-connected biomass generating capacity in the U.S., much of it associated with the wood and wood products industry - which obtains more than half its electricity and thermal energy from biomass.

Gasification technology has little presence in the market at this time. The exceptions are certain refineries that gasify petroleum coke, and several large utility power stations that have been built to demonstrate 200 to 400 megawatt-scale technology as part of the clean coal program.

With an estimated 14,000 MW of annual worldwide installed generation capacity, biomass power is the largest source of non-hydro renewable electricity in the world. Currently, the U.S. is the largest BioPower generator at 7,000 MW. Approximately 80% of this total is generated in the industrial sector, primarily in the pulp and paper industry.

Technology Outlook

Electricity from biomass meets about 1% of the total U.S. demand. Direct-fired biomass systems remain the most common technology deployed. Future attention may turn more to gasification because the electricity derived from the quantity of biomass consumed currently could be roughly doubled if gasification/turbine-based power systems were employed instead of direct-fired combustion systems. The average efficiency of existing biomass-fired capacity is about 20%. Efficiency of biomass/turbine systems could achieve a 35-40% range, which is comparable to high-efficiency coal-based systems, but can be achieved at a smaller scale of operation. This option would pertain to high-pressure gasification systems. Low- or atmospheric-pressure systems would be more suitable to produce burner fuel and ultimately hydrogen for fuel cells.

Conventional fuel prices and environmental considerations will dictate the technology development path of biomass systems for industrial uses. The positive environmental drivers relate to the fact that biomass conversion closes the carbon cycle, and gasification-based systems, due to their high efficiency, reduce CO emissions per megawatt of power generated over conventional biomass power plants. Biomass is also lower in sulfur than most U.S. coal. Since gasifiers operate at much lower temperatures than combustors, gasification allows a wider variety of feedstocks, such as high-alkali fuels, than may be technically feasible for direct combustion systems. High-alkali fuels (such as switchgrass, straws, and other agricultural residues) often cause severe corrosion, erosion, and deposition problems on heat transfer surfaces in conventional combustion boilers

Looking further ahead, gasification of biomass or biomass and coal could become a fuel source for fuel cells. Before that, gasification could also supplement natural gas supplies, provided costs of natural gas rose over $5.00 per million Btu and stayed at that level.

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Photovoltaic Systems

Photovoltaics (PV) is the name for solar technology that converts sunlight directly to electricity (direct current, DC). Solar cells made of semiconductors are assembled into modules used singly or in arrays to make up systems that include batteries and a battery charge controller for energy storage for remote power for DC electric applications. Systems with an inverter convert the DC power the panels generate to alternating current (AC) and feed any excess power back to the utility. Remote power or uninterruptible systems will combine batteries and an inverter to deliver reliable AC power. These "balance of system" components mount, and sometimes tracking modules follow the sun, store and condition electricity, provide safety, and control energy use. Durable and reliable, PV modules have no moving parts and should last 20-30 years.

PV modules have their power output rated in peak watts, a figure derived from standard operating conditions of 25 °C and insolation of 1,000 W/m^2. They have been engineered to withstand extreme temperatures, severe winds, and impacts from 1-in. hail at terminal velocity (55 mph). Manufacturers warrant modules against power degradation for 10-20 years. Most PV arrays for stand-alone systems consist of crystalline silicon PV modules that range in size from 50 to 80 peak watts. Very small systems, sensors for example, can operate with 5-watt panels. Larger systems can range from 500 watts to 100 kilowatts, and even 1-megawatt systems have been installed.

Photovoltaic panels account for about one-half the installed cost of a system. Storage batteries are needed, and the two most common types used in PV systems are flooded lead acid batteries that require periodic maintenance (addition of distilled water and equalization), and valve-regulated, sealed lead acid "maintenance-free" batteries. Other Balance of System components include battery chargers and controls, inverters for AC systems (which can be grid tied), and all the electrical interface wiring and fixtures.

PV Cell Technologies

Crystalline silicon (c-Si)

Crystalline silicon is the leading commercial material for photovoltaic cells, and it is manufactured in several forms: single-, mono-, multi- or polycrystalline. Single cell production starts with quartzite to create metallurgical-grade silicon, which is then refined to a very high state of purity. Cells are grown out of molten polysilicon using a single crystal seed. Ingots are then sliced into wafers, which are processed into PV cells that are mounted into a module. Semi- and polycrystalline silicon cells are most often produced with a casting process that forms molten silicon into an ingot. Special processing is required to eliminate grain boundaries that limit cell efficiency and output. The ingots are sliced into wafers and finished into cells. Semi- and polycrystaline technology captured a third of the market in the early 1990s.

Thin Films

These cells consist of layers of semiconductor materials only a few micrometers thick, attached to an inexpensive backing such as glass, flexible plastic, or stainless steel. Materials include amorphous silicon (a-Si), copper indium diselenide (CIS), and cadmium telluride (CdTe). Less semiconductor material is required for thin films, meaning they cost less to manufacture; however, they do not convert sunlight as efficiently. Consequently, a larger array is required for the same amount of peak power output as a crystalline silicon array.

Group III-V Technologies

Based on Group III and V elements in the Periodic Table, these materials have high conversion efficiencies under either normal or concentrated sunlight. Single-crystal cells of this type are usually made of gallium arsenide (GaAs). Gallium arsenide can be alloyed with elements such as indium, phosphorus, and aluminum to create semiconductors that respond to different waveband energies of sunlight.

High-Efficiency Multijunction Devices

Multijunction devices stack individual solar cells on top of each other to maximize the capture and conversion of solar energy. The top layer (or junction) captures the highest-energy light and passes the rest on to be absorbed by the lower layers. Gallium arsenide and its alloys are commonly used, as well as amorphous silicon, copper indium diselenide, and gallium indium phosphide. Although two-junction cells have been built, most research is focusing on three-junction (thyristor) and four-junction devices, using materials such as germanium (Ge) to capture the lowest-energy light in the lowest layer.

Concentrating Photovoltaic Collectors

Concentrating photovoltaic collectors use devices such as Fresnel lenses or reflectors to concentrate sunlight onto a solar cell. Gallium arsenide cells and silicon cells have been deployed with concentration ratios from 20 to 1,000 suns, which reduces the expensive specialized semiconductor area significantly per square foot of solar collector. Concentrating collectors are usually mounted on a two-axis tracking system to point the collector at the sun.

Applications for Glass Plants

Stand-alone photovoltaic systems produce power independently of the utility grid. While the first choice for power is a utility line connection, high interconnection costs can make PV a sensible choice. Factors that contribute to high line-construction costs include:

- Long distance to the nearest utility distribution line;
- Unavailable utility easements;
- Roadways or parking lots that block access or complicate construction;
- Steep or rugged terrain;
- Requirements for buried lines;
- Requirements for environmental impact studies; and
- Requirements for archaeological studies.

In locations even as close as 300 to 1,200 feet to a power line, stand-alone photovoltaic systems can be more cost-effective than grid connection. Utilities will even install a very small PV panel to service a micro-load right on their own power poles because it is cheaper than installing a step-down transformer. For a manufacturing plant complex, small PV systems can power sensors for security or monitoring systems, or for data collection and transmission. In a factory complex, 20-watt to 2,000^{+}-watt arrays can power outdoor lighting, fence chargers, fluid pumps, telecommunications, remote cathodic protection, and plant traffic warning signals. Because direct-coupled systems operate only during daylight hours, they need no electrical storage; however, most systems rely on battery storage. Hybrid systems can combine solar power with additional power sources such as wind or diesel.

Grid-connected photovoltaic systems supply surplus power back through the grid to the utility and take power from the utility grid when the site system's power supply is low. These systems do not require battery storage, and where utilities have been required to "net meter" PV systems, the owners sell excess power back to the utility at the retail rate. For a manufacturing complex larger systems, from several to tens of kilowatts in size, can be used to maintain batteries for uninterruptible power for sensitive, critical factory control or data storage systems. They are a form of insurance for power quality should utility power go down.

With an invertor, either grid tied or stand-alone PV systems can run any electrical load. If a substation in a plant were having difficulty meeting an increase in the electric power load it served, a photovoltaic system could be installed on the load side to supplement the power without having to upgrade the substation. It might defer such investment for several years or permanently. Such systems will also reduce demand charges.

Economics

Assessing economics of a PV systems requires two steps. The first involves the initial equipment and installation cost of the PV system versus the cost of connecting to a utility power line. For example, a movable security barrier installed at a government site required $15,000 to run a utility power line to power a hydraulic motor. The equipment cost of a stand-alone PV system to perform the same task would have been $7,500 to $8,500. Further, it would have been more secure. Other PV systems benefits related to comparative first costs include:

- Increased siting flexibility;
- Less installation lead time required and fewer compliance hurdles;
- Fewer disruptions associated with installation;
- Improved aesthetics;
- Increased power reliability; and
- Portability and modularity that facilitates expansion.

The second assessment step involves calculating the delivered cost per kilowatt-hour of electricity over the life of the system. Most such assessments are done based on simple payback, and for photovoltaics, simple payback can exceed 20 years for a system if the capital cost is simply divided by the total delivered kilowatt-hours. Calculating life-cycle cost, or net present value, of a photovoltaic system gives a more accurate assessment and takes into account such savings as permitting, running power lines and other costs to connect to the grid, and lower maintenance and service costs. In addition, commercial purchasers of a photovoltaic system are eligible for a 10% permanent federal business energy investment tax credit; plus, they can depreciate the basis in five years, with 35% taken in the first year. Besides the federal incentives, 29 states have corporate tax incentives for renewable energy, and in 12 of these, photovoltaic systems are covered. The incentives further lower the purchase cost of an installed PV system. See Appendix B for more details. Other states offer rebates. In California, $4.50 per peak watt, or 50% of the system installed cost is available to commercial purchasers of photovoltaic systems. When the installed system cost is cut in half, and utility retail rates are more than 15 cents per kilowatt-hour, PV systems move into the competitive range.

Rules of thumb for cost estimating relate to dollars per peak watt installed. Small systems with 10- to 100-watt panels and a small battery and charge controller will be about $11 to $13 per peak watt. For larger systems, especially those that are grid tied and have no battery storage, installed costs can be less than $8.00 per peak watt. Consumers must be aware, however, that energy output compared to system rating can be 15 to 30% less due to inefficiencies inherent in the system. Thus, economic attributes of each system installed are site specific and must be calculated taking site orientation, weather conditions, all the costs, incentives, and savings into account. When this is done properly, many photovoltaic system applications can be economically attractive.

Environmental

The environmental impact of an operating PV system relates to system scale. For very small systems, there are practically no impacts except for proper lead acid battery disposal. For larger stand-alone systems, the batteries require a vented enclosure and safety attention. Workers around larger PV systems must be trained carefully and employee awareness raised because high-voltage DC current can be more dangerous than AC.

Silicon-based PV panels pose few environmental problems with regard to disposal. Cadmium telluride and gallium arsenide panels that have reached the end of their useful lives have to be disposed of properly. The materials are fully encapsulated and when they are operating are not an environmental hazard. Overall, photovoltaic systems have a positive environmental impact. The energy it takes to produce a silicon crystal PV panel is recovered in 4 to 7 years, and new thin film materials will cut the recovery time to about 1 year. PV systems offset utility power, or small diesel or gasoline engine generators, all of which pollute. Each installed kilowatt of PV displacing fossil-generated electric power offsets 35 pounds of NO_X, and 20 pounds of SO_X per year.

Market

The current world photovoltaics industry is a $2 billion business. Over the last 5 years, production has increased 25% per year. The largest application for photovoltaic systems has become grid-interconnected power. In 1998, U.S. manufacturers shipped about 14 megawatts of modules for this application. Remote power systems and communications systems are the second and third largest applications, with U.S. manufacturers shipping over 16 megawatts of modules for these two. Costs of PV modules fell steadily until the late 1990s, and have stabilized around $4.50 per peak watt wholesale for the last 3 to 4 years. The modules and balance of systems technologies have proven to be highly reliable and represent a mature technology, with crystalline silicon dominating the market.

Government incentives in the U.S. and abroad have been largely responsible for the growth of grid-interconnected power systems. Appendix B in this Guide shows that in some states, 50% of the cost of a PV system will be subsidized, which has stimulated this market growth. Small remote systems remain very cost effective in many applications, and all sizes of remote systems account for 8 megawatts of U.S. module sales each year.

Technology Outlook

Looking ahead, cost reduction goals from the photovoltaics industry technology road map are for systems to fall to $3 to $4 per peak watt AC installed by 2010. For modules, the goals are to reduce costs to $0.50 per watt and have 18 to 20% conversion efficiencies. New as well as progressive advances in technology and efficiency will be forthcoming to meet the goal. The federal government continues to invest about $80 million per year in photovoltaics R&D and has focused most of its attention on thin film technologies. Large integrated oil and large electronics/semiconductor companies are involved in the industry along with smaller independent companies. Private sector investment will continue to help bring down costs.

In the near term, there are no expected breakthroughs that will radically lower PV system costs. The industry has been so price competitive over the last 15 years, that until the mid-1990s, very few PV manufacturers were profitable. They are now recouping sunk investments, and prices should remain fairly consistent over the next few years.

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Wind Turbines

In the 20th Century, wind machines progressed from their historic role of producing mechanical power to generating electricity. The United States helped establish the modern era of wind power generation in the early 1980s when developers installed multiple wind turbines in wind farms to generate and sell electric power to utilities. Several generations of technology have ensued and commercially available systems range from 200 watts to over 1 megawatt in generating capacity. Wind energy systems are now competitive with fossil fuel burning power technologies on a life-cycle cost basis.

Glass manufacturers could consider adding wind power to their supply mix to help meet growing demand for electricity being used to boost temperatures in melting furnaces. Companies that are turning to oxygen burners are also increasing their electric loads (about one-third the cost of oxygen is electricity). Turning to clean electric power from wind could gain air emission offsets or meet CO_2 reduction targets. To access wind-generated electricity, a manufacturer could contract for a portion of the electricity being generated in an existing wind farm, or if located near a wind resource area, a glass company could invest in its own wind turbines and wheel power to its plant over existing utility lines. The result would be a secure, lower cost supply of electricity over the life of the wind turbines.

Current large wind turbines for producing electricity consist of four main components: the rotor (the blade and hub that rotate and the attached shaft), the electrical generator, a speed-control system, and a tower. For a horizontal axis machine, a nacelle on top of the tower holds the rotor. Large wind machines use fail-safe shutdown systems such as a device to turn (feather) the blades. Some turbine designs include blade tip airfoils to control speed.

Towers are an important and significant cost consideration because wind velocity increases with altitude. Current wind turbine towers average about 100 feet and are expected to increase to 230 feet by the year 2005. For large machines, steel tubes are most commonly employed now.

Generators convert the mechanical shaft energy to electric power and are typically generic units not specifically designed for wind turbine applications. Because the shaft rotational speed is low, around 60 revolutions per minute, most wind systems require a transmission system to increase the rotational speed (e.g., 1,800 revolutions per minute) required by most generators.

Economics

Like hydroelectric and solar technologies, a wind energy system's up-front capital investment dominates costs, and no recurrent fuel cost stream exists. An intermittent resource, wind regimes are rarely constant daily or throughout the year. On an annual basis, wind system capacity factors range between 20 and 35%, meaning over 12 months, it will deliver between 20 and 35% of its rated output. While wind without energy storage is not a baseload power technology, the last 15 years have demonstrated that wind farms effectively complement utility power systems.

Very small turbines can cost $2,000 per kilowatt just for the machine. Tower, mounting and electrical interconnection will add more to the installed costs. Larger wind turbines from 200 to 1,500 kilowatts in size that are installed in wind farms cost approximately $1,000 per kilowatt installed. Not counted are infrastructure costs related to site preparation, land costs, and the costs of connecting to a power grid.

The baseline for current technology for a new 50-MW wind farm is an installed cost of $1,000/kW, a 30% capacity factor, and operations and maintenance (O&M) expenses less than 1 cent per kilowatt-hour (0.65 cents/kWh). In an excellent wind site, such a wind farm should generate electricity at a levelized or life-cycle cost of 4 to 5 cents per kilowatt hour. The Department of Energy anticipates that further technology improvements will lower the average cost of wind power to 3 cents per kilowatt hour in 2004 for high wind speed sites.

A wind turbine typically requires a minimum wind speed of 9 miles per hour (mph) in order to generate power. Economic sites for small wind turbines connected to the grid require an annual average wind speed over 11 mph (5 meters per second). For wind farms to be cost effective with current technology, average annual wind speed needs to be 13 mph (6 meters per second) or more. If a wind turbine is used in a more remote application, other factors determine competitiveness related to the long-term cost of conventional options.

The Federal Energy Policy Act of 1992 created a wind energy production tax credit to help make wind energy more competitive with conventional energy sources. The tax credit amounts to 1.5 cents per kWh (adjusted for inflation) for electricity produced using wind resources. It therefore rewards actual electricity generation, rather than equipment installation. The credit applies to the first 10 years of production for wind turbines installed between December 31, 1993, and December 31, 2003.

Environmental

Wind power systems have little impact on the environment compared to conventional power sources. Three concerns are: audible and electromagnetic noise produced by the rotor blades, aesthetic (visual) impacts, and periodic bird kills. Technological development and/or proper siting of multiple turbine wind plants have resolved or greatly reduced most of these problems.

The largest machines in the market are 20 stories tall and have blades that span 300 feet. Approximately 50 acres (20 hectares) of land are required per MW for each utility-scale turbine. However, much of the land is actually unoccupied and can be used for farming, ranching, and other activities. Although wind turbines generate some noise, a 300 kW turbine creates only 45 dB of noise at a distance of about 650 feet (200 m). This noise is usually masked completely by background noise or the natural sound of the wind.

Market

Wind farms selling power to utility companies as independent power producers dominate the market. Worldwide, 6,500 new megawatts of wind power electric capacity were installed in 2001, bringing total installed capacity to about 24,000 megawatts. In the U.S. alone, close to

2,150 new megawatts came on line in 2001 and 2002, and U.S. wind farms produce about 10 billion kWh annually.

If a manufacturing facility sought to diversify its energy supply with a renewable energy system, wind could be feasible if:

- The facility has access to good wind resources, i.e., the site has been designated as Wind Class 3 or higher;
- The current cost of electricity at the facility is 8-12 cents/kWh, or if peak demand charges are high;
- Diesel oil or another fossil fuel is transported to the site for power generation; and
- The facility is having trouble complying with air-pollution regulations.

Small turbines can also be applied economically to charge batteries for small loads far from an existing utility line. These applications include:

- Telecommunications;
- Remote structures;
- Cathodic protection;
- Navigation aids;
- Monitoring/security;
- Pumping/irrigation;
- Desalination/treatment;
- Crisis response; and
- Uninterruptible power.

Hybrid wind systems with a photovoltaic system and battery storage have been competitively installed to replace diesel generated electricity. If a manufacturer had a situation that required a stand-alone 20- to 30-kW diesel-generator, a system to replace it (the diesel serves as backup) could consist of two 10-kW wind turbines; one 12.6-kW photovoltaic solar array; a 300-kW battery bank; a 30-kW, 3-phase bimodal inverter providing 208/120 AC electricity; and a system controller to monitor and regulate power from the wind turbines. This system is capable of eliminating consumption of about 17,500 gallons of diesel fuel and at least 120 gallons of motor oil each year.

Worldwide, the wind power industry has reached $1.5 billion in sales annually. Wind energy systems have improved dramatically in the last 20 years and will continue to make significant gains.

Technology Outlook

The predominant technology is the horizontal axis machine; however, some development continues on vertical axis, or Darrieus, technology. Over the last fifteen years, the average cost of wind power has dropped by more than 80%. In the early 1980s, the rate for wind turbine availability to generate was about 60%. Today, it has risen to 98%. More technical advances and cost improvements will be forthcoming, and wind energy contracts with utilities for 3 cents per kilowatt-hour levelized over time in the United States are imminent.

From 1990 to 1997, worldwide market expansion of wind power capacity averaged 25.7% per year. Technical developments will continue for all the key components of wind energy systems. Glass companies are involved in carbon and carbon/glass composite work for blades. Towers, rotors, and drive trains can all be improved or made less costly. The U.S. Department of Energy launched a partnership effort with the wind industry in 1992 to rapidly develop a new generation of innovative, low-cost wind technologies to compete in global energy markets. The first turbines created under these partnerships are already on the market, and a new generation of turbines began arriving on the market in 2003.

In 1996, the DOE program selected two development proposals for megawatt-scale machines. The innovations will include a direct-drive generator alone or in combination with a conventional gearbox. Significant departures from conventional rotor design are anticipated, including purpose-designed airfoils and low-solidity, flexible blades with individual pitch control. Taller, low-stiffness towers are expected, as are advanced control strategies to optimize energy capture and reduce loads. Extremely tall (100 meter or 328 feet) guyed towers should be forthcoming to capture wind potential in the Midwest. The Department of Energy has projected a 20% reduction in cost for a next generation of equipment.

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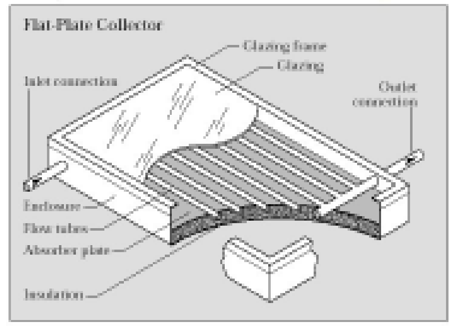
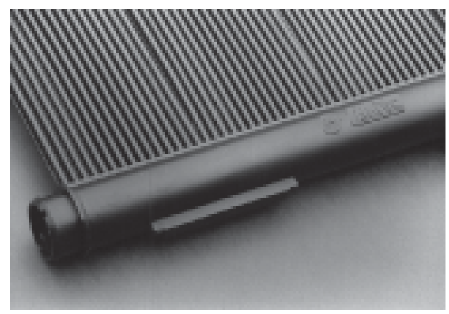
Flat Plate Solar Thermal Systems For Low and Medium Temperature Solar Thermal Applications

Flat Plate Solar Collectors are used to collect thermal energy for applications requiring heat from 80 to 300 °F. The simplest and most produced flat plate collector is a metal, plastic, or rubber compound black tube mat commonly used for swimming pools or process water heating (80 to 110 °F). The fluid to be heated is pumped through tubes that form the collector or are bonded to an absorber plate. These collectors are very efficient when they operate at near ambient temperatures.



Glazed Flat Plate Collector

To be more efficient at higher temperatures, medium-temperature collectors have a transparent glass or plastic cover over the absorber and insulation for the back and edges of an enclosure to isolate the absorber from the outside. A transport fluid (water, antifreeze, oil, alcohol, or air) transfers the energy from the absorber plate to the load or storage. The most common medium-temperature flat plates have a single transparent cover and use copper or copper-clad metal absorber plates and tubes. [See the transpired collector technology brief for a description of one type of air collector system.]



Unglazed Flat Plate Collector

A variation of flat plate collectors to increase efficiency is to surround the absorber with a vacuum. The absorber consists of a metal strip and bonded pipe mounted inside a sealed glass vacuum tube. The glass tubes are mounted in rows and connected to a single exterior header. The vacuum lowers the heat losses from convection and conduction and helps vacuum tube collectors achieve higher temperatures (170-350 °F), so they are appropriate for commercial and industrial applications.

The balance of system components for closed- or open-loop solar fluid or space heating systems consists of sensors, a controller, a pump or fan unit, and heat exchanger and/or storage tank. Solar thermal systems can be installed without controls and pumps in a thermosiphon or batch heater configuration. When the water storage tank is plumbed above the collectors in a system, natural convection will circulate the heat transfer fluid. Solar batch heaters store water in the collectors themselves and refill from the water main when water is withdrawn for the application.

Economics

Solar water heating can be used effectively throughout the country. Although the dominant factor in determining effectiveness for solar water heating is the available solar resource, one should not dismiss using solar water heating because a facility is in a cloudy area. Important other factors to consider are colder water supply temperatures, longer heating seasons, and higher costs for electricity or fuel.

The price for unglazed panels for low-temperature applications is about $4.00 per square foot. Depending on the site, installation can add $3.00 to $6.00 per square foot. Larger systems will have lower costs per square foot. An unglazed flat plate solar collector system to heat well or pond water to 100 °F is one of the most cost-effective solar applications, and over a five-year period is capable of delivering low-temperature energy at $2.00 per million Btu or less.

For small solar water-heating systems, the most cost-effective size will often be one that just meets the full summer demand and approximately two-thirds of the year-round demand. Including enough capacity to meet more of the winter demand reduces cost-effectiveness because excess capacity is wasted in the summer. For industrial process applications the same general rule could apply; however, analysis using one of several solar simulation programs available is the best approach to design a system.

Example of Industrial Scale Solar Thermal System Delivered Energy Cost

Output of highest rated polymer olefin flat plate solar panel = 1,042 Btu/ft²/hr
Assume 900 Btu/ft²/hr for 4.5 peak hours per day = 4,140 Btu/ft² produced on an average day
Operate 300 days = 1,242,000 Btu/ft²/year
System thermal losses of 10% reduces yield to 1,117,800 Btu/ft²/yr
Installed at $8.00 per square foot
Delivered energy in year 1 = $7.15 per million Btu
Two years of operation lowers cost to $3.58 per million Btu
Five years of energy delivered to load costs $1.43 per million Btu

A Federal Energy Management Program case study for a solar water heating system with a 500-gallon storage tank and four glazed medium-temperature flat plate collectors totaling 200 square feet documented an installed cost of $7,804. This amounted to $39.02 per square foot, a typical figure for this kind of system. This system saved 9,394 kWh per year and had a 9-year simple payback with utility power costing $0.092 per kilowatt-hour. For a commercial owner, the payback would be shorter because the federal tax credit would lower the initial purchase cost by $780, and the system is fully depreciated in 5 years. With the federal incentives, the simple payback is between 5 and 6 years. Some states offer as much as a 35% investment tax credit for solar, which would further reduce the simple payback to about 4 years. See Appendix B for more information on incentives.

Environmental

The only air emissions associated with a solar water heating system would come from electricity used to run the system control and any pumps. Flat plate collector systems are most often mounted on building roofs. In metal collectors all the material is salvageable.

Market Status

Flat plate solar collector technology and systems are mature technologies. One million residential and 200,000 commercial solar water-heating systems have been installed in the United States. The technology is well developed, and today's solar water-heating systems are well proven and reliable when correctly matched to climate and load. Most installations are for water heating; however, flat plate collector technology can also provide energy for absorption or desiccant cooling systems, process water for industry, hot air for drying, or pre-heat make up water for steam systems.

The current market consists of a relatively small number of manufacturers and installers that provide reliable equipment and quality system design. The Solar Rating and Certification Corporation, a quality assurance and performance rating program instituted by a voluntary association of the solar industry and various consumer groups, makes it easier to select reliable equipment with confidence.

Technology Outlook

Industry has built a solid reputation for solar thermal systems by emphasizing quality and durability. Costs can still fall through economies of scale if manufacturing production levels increase. Technical innovation in materials is most likely to have the largest mid-term impact on system performance and cost.

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Solar Thermal System Advantages

FLEXIBILITY
- Can deliver heat from 100 to 330 °F
- Can match practically any load
- Interface easily with conventional systems

STORAGE
- Store energy easily for later use

MODULARITY
- Incremental load matching

Parabolic Trough Solar Thermal Systems

Parabolic troughs are a line-focus solar concentrator technology. When oriented to the sun, solar trough collectors reflect parallel beams of light onto a linear receiver located at the focal point of the parabola [Figure 2-1]. The receiver is a pipe that transports a circulating working fluid to collect thermal energy at the collector and transfers it to the load. Because parabolic troughs concentrate sunlight onto a small receiver, convection, conduction, and radiation heat losses are minimized compared to a flat plate solar thermal collector. Sandia tests of an Industrial Solar Technology Corporation trough concentrator have verified that thermal efficiency at 212 °F (100 °C) above ambient temperature was 68%, and at 302 °F (150 °C) above ambient it was 61%. Concentrating solar collectors can serve thermal loads ranging from 100 °F (38 °C) for heating process water to 550 °F (288 °C) for generating steam for power production.

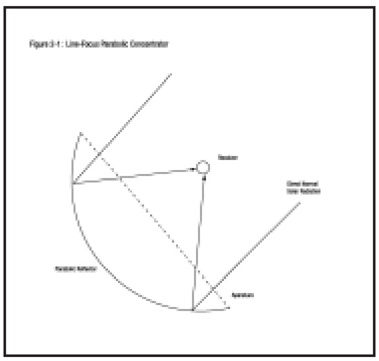

Figure 2-1: Line-Focus Parabolic Concentrator

Support and frame structures are typically fabricated from steel or aluminum, and systems are designed to last 20 to 30 years. Several reflective surfaces can be used for the concentrating mirror, including silvered glass, aluminized and silvered plastic films, and polished aluminum. The amount of solar radiation reflected to the receiver is a function of the optical properties of the concentrator, mainly: the reflectance of the mirror, the optical intercept that determines how much of the reflected light is incident on the receiver, and the transmittance of the glass envelope around the receiver. Heat loss is a function of the thermal properties of the receiver: the absorptance and emittance of the selective coating applied to the absorber, and whether the annular space between the absorber and the glass envelope is air-filled or evacuated.

Economics

The levelized, or life-cycle, cost of solar thermal energy to make steam delivered from parabolic concentrators ranges from $8.00 to $10.00 per million Btu delivered to the load. This includes operation, maintenance, and all other costs.

For parabolic trough solar water heating, the Federal Energy Management Program has estimated that in the Western U.S., at an installed cost of $32.00 per square foot of collector array, the delivered energy cost will range between $8.00 and $10.50 per million Btu. These figures are for a federal government installation. Two key factors that determine actual levelized costs are system size and insolation levels. Capital cost is lower per square foot of array the larger the solar thermal system. Economies of scale as sales grow to support continuous production will lower costs further in the future. In addition, new reflector technology is being developed that will both lower costs and increase thermal efficiency. Currently, for small systems with a 7,200-square foot array, a rule of thumb cost estimate is $37.00 per square foot. As system size increases, costs with current technology and limited production can drop to less than $30.00 per square foot installed, and future costs are projected to fall to $25.00 or less per square foot just through growth of production and modest material improvements.

For electric power production various mirror configurations can be used to concentrate sunlight and produce high temperatures (600-1,300 °F), which then heat an intermediary fluid (oil or molten salt) or produce steam directly to power a Rankine cycle engine. Thermal energy storage allows these systems to produce steam and power to match the load, which adds much to their economic value.

Current solar power technologies are in the 10-12 cent/kWh range; future costs have been projected to drop into the 3.5-6.2 cent/kWh range by 2020.

Environmental

The only air emissions associated with a parabolic trough water heating or steam producing system would come from electricity used to run the tracking mechanism, the system control, and the pumps. For a small solar thermal electric system, from 200 kW to 1 MW, the only associated air emissions would come from any purchased utility electricity to operate the system. Small solar thermal electric systems can use self-contained organic Rankine cycle engines for the prime mover. Current technology is using pentane as the operating fluid. As the scale of the power system increases, steam turbines can be the prime movers. For large 30- to 60-MW power plants, the collectors use a high-temperature oil as the heat transfer fluid and conventional steam turbine generators as the prime mover.

Parabolic trough systems are most often installed on the ground. Ground installations require an environmental assessment similar to that involving installation of a field of parking lot street lights. (The only ground contact is through cement casings for the support pylons and support for the thermal heat transfer piping). The very large solar electric systems in California required an environmental impact study because of the desert siting and some measures to protect tortoises were instituted. Trough systems can also be mounted on buildings. These systems can create emission offsets or be used to expand energy use in plants without adding any air emissions. If a heat transfer oil is used, leaks would amount to an environmental spill. The oil is combustible also. For most industrial applications, pressurized water would be the heat transfer fluid of choice.

Market Status

Parabolic trough systems have been installed commercially in the United States since 1984. Over 27 million square feet of Luz International collectors were installed in California totaling 355 megawatts of electric power plants under independent power producer regulations. Industrial Solar Technology was the only U.S. company installing commercial trough systems in the 1990s. Installed in energy service contracts, these have been for water heating. In July 2002, Arizona Public Service Company issued a tender for a 1-megawatt trough-organic Rankine cycle system that went to Duke Solar, now named Solargenerix. Solargenerix was awarded a 50-MW power plant contract in Nevada in 2003.

Troughs compete with flat plate thermal collectors for low- and medium-temperature installations, but they are superior for any application requiring output temperatures above 200 °F. Even though current production is limited to individual jobs, in many applications they are less expensive to install than glazed flat plate solar thermal collectors.

Technology Outlook

Parabolic trough technology is commercially and technically proven. It is not in mass production; consequently, as systems begin to be installed regularly, costs will come down substantially. The rise of natural gas prices to $4.00 per million Btu in 2002 will open more markets for these systems. Solargenerix has been marketing a new version of the Luz International LS-4 collector for electric power systems and has been developing its own roof-integrated trough system. Industrial Solar has begun developing a glass-steel concentrator, experimented with polished aluminum reflectors, and been involved in several overseas projects for steam production and electric power systems. The European Union also assessed Industrial Solar Technology troughs in a comparative study for the Iberian Peninsula market and determined that Industrial Solar troughs were the most cost-effective solar thermal technology. The technology is ready for market pull.

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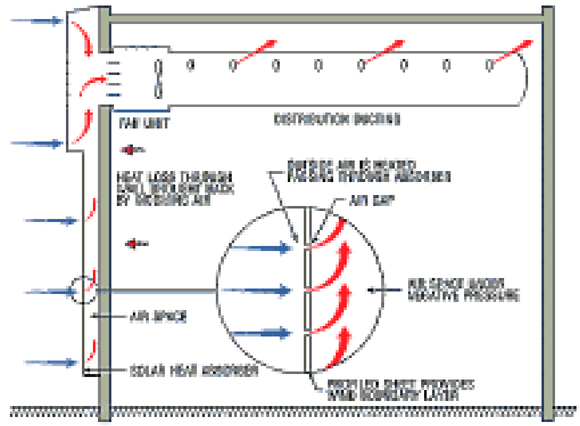
Solar Thermal Transpired Collectors

Transpired solar collector technology is remarkably simple. A dark, perforated metal wall is installed on the south-facing side of a building, creating a gap between it and the building's structural wall. The dark-colored wall cladding becomes a large solar collector that converts solar radiation to heat. When installed on the south-facing side of a building, it receives maximum exposure to direct sunlight during the fall, winter, and spring seasons. It can be roof mounted as well to make an air collector.



Solar heat gathered by the collector is transferred to outdoor air drawn into the building through the ventilation system intakes. Fans associated with the building's ventilation system mounted at the top of the wall draw outside air through the transpired collector's perforations into a gap between the collector and structural wall. The thermal energy collected is transferred to the air passing through the holes. The fans then distribute the heated air into the building through ducts mounted from the ceiling.

Solarwall can be incorporated into new building construction or retrofit onto existing exterior walls. The technology is ideally suited for buildings with at least moderate ventilation requirements in locations with long heating seasons.

U.S. and Canadian government research centers have extensively tested transpired solar collectors systems. Canada alone has spent over $500,000 on testing and field monitoring installations at Ford, General Motors, and McDonnell Douglas. To speed adoption of energy-efficient and renewable technologies in the federal sector, the U.S. Department of Energy Federal Energy Management Program has issued a technology alert on transpired solar collectors.

Conserval Engineering Systems, Inc., refined unglazed transpired solar thermal collector technology with some assistance from an Energy-Related Inventions Program grant from the U.S. Department of Energy.

Economics

Solarwall offsets a substantial heating load from the building HVAC system. The system is a solar thermal technology and eligible for federal tax incentives for commercial and industrial applications. Transpired solar collectors heat ventilation air at substantially lower costs, plus indoor air quality can be improved by bringing in more outside air. For factories that must meet OSHA standards for air changes, a transpired collector system can heat this air for about the cost of running the fan.

The payback can be immediate to a few years, and this technology has a better simple payback than many other building products, such as high-efficiency windows and heat recovery devices. An added benefit can be publicity or improved public image for a company that takes a leadership role in utilizing renewable energy.

Transpired solar collector cladding is less expensive than many architectural wall materials, but is slightly more expensive than metal siding. A system installed on new construction costs approximately $5 per square foot, where as retrofit costs approximately $10 per square foot. Commercial solar thermal installations receive a 10% investment tax credit from the federal government; plus, some states give up to a 35% tax credit, which makes the payback period even shorter. (See the economic analysis below). Estimated payback with a 10% federal tax credit for a 20,000 square-foot system retrofit onto an existing building in Syracuse, New York, would be approximately 7 years. This payback calculation does not take into account any fuel price escalation over the seven years, nor does it factor in conversion efficiency losses of the gas-fired air heating system.

During summer, a transpired collector system will cut cooling loads, for further savings. The cladding stops sunlight from reaching the main wall and acts as a shade. The solar thermal system requires no maintenance and will last as long as any other metal cladding material. Any fans or dampers attached to the system are required in any event and would have the same maintenance as an ordinary fan.

A 20,000-square foot Solarwall installed to an existing building in Syracuse, New York, would generate 2,571 million Btu of energy per year and save 155 million Btu through its insulating properties. Factoring in a 75% efficiency factor for the supplanted fossil energy heating system would make the total annual savings amount to 3,635 million Btu. If natural gas were priced at $6.75 to the user, the annual savings would be $24,536. For a retrofit installation with an installed cost of $10.00 per square foot, the simple payback would take 8 years. If installed on new construction for $5.00 per square foot, the simple payback drops to 4 years.

Environmental Impact

Installing a transpired solar collector has the same impact as putting a new facade on a building. The environmental gains come from cutting use of fossil fuels or electricity for heating ventilation air. Solarwall is made from steel and after its life may be recycled.

Market Status

Transpired solar collector systems have been installed commercially since the early 1990s. The market has developed steadily over the last decade, and systems have also been sold abroad.

Technology Outlook

Technically, transpired solar collectors are a mature technology. The manufacturer has recently added a new production facility and now offers a wider selection of colors. Costs for the technology can still fall as production levels increase due to economies of scale.

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Section 3: Building Technologies Applicable to Plant Facilities

Several advanced building technologies developed with assistance of EERE are currently available on the commercial market.

Technologies

Insulating Forms and Structural Panels
Cool Roof Technology
Desiccant Dehumidification and Cooling
Air-to-Air Heat Exchangers
Compact Fluorescent Lighting
Sulfur Lamps
Light Emitting Diode (LED) Lighting
Electronic Ballasts
Reflectors
Fiber Optics
Task Lighting
Lighting Controls
Solar Daylighting
Aluminum Roofing System
PowerGuard®
WhiteCap®
RR-1 Insulating Screw Cap
High-Efficiency Direct-Contact Water Heater
Solar Skylite Water Heater
Radiant Heating Panels
High-Efficiency Dehumidifier
SOLARWALL®
IceBear: Thermal Energy Storage for the Small Packaged Terminal-Air Conditioning Unit
Insulation Containment Apparatus (The Ultimate "R")
GibBAR-Wall™ System
A Dual-Fuel Conversion System for High-Output, Medium-Speed Diesel Engines
PowerRIM®

The following technologies that are applicable to buildings are covered in the Distributed Generation Resources section:
Flat Plate Solar Collectors
Parabolic Trough Solar Collectors
Solar Thermal Transpired Collectors

Glass Factories as Buildings

It is not easy to get manufacturing managers or staff who are focused on increasing production and sales to pay attention to their facilities as energy consuming buildings. However, energy performance of a building structure not only affects utility bills, it can profoundly affect the productivity of the people who work in it. In the Office of Energy Efficiency and Renewable Energy, the Building Technologies Program pursues efficiency through many avenues, from development of more efficient energy using products and better construction systems and design to energy labeling and standards development. Many advances in building technology can be used for manufacturing structures. The following highlights a few technologies the EERE Building Technologies Program promotes related to the building envelope, heating and cooling, and lighting that apply to manufacturing facilities.

Insulated Concrete Forms

Foam blocks called insulated concrete forms (ICFs), represent a new style of concrete construction for commercial structures. Hollow blocks are pounds lighter than standard masonry blocks because they are made of expanded polystyrene. They either interconnect and stack together or form separate panels connected with plastic ties. During construction, the forms are filled with concrete, becoming a permanent part of the wall assembly that adds a 2-inch thick layer of foam insulation to each side of the wall. Reinforcing bars can be added for earthquake safety. With an R-value of 21 and higher, foam block walls are so well insulated that for small buildings they can cut heating and cooling costs up to 75%. The added insulation allows the heating and cooling system components to be downsized by as much as 50%. The walls are fire, earthquake, and termite resistant, and the layers of foam insulation provide excellent soundproofing as well as backing for drywall on the inside and stucco, lap siding, or brick on the outside.

For residential construction, the U.S. Department of Housing and Urban Development has determined that structures using ICF systems had a small increase in construction costs compared to conventional construction that was offset by the energy savings.

GLASS INDUSTRY BUILDINGS

1,026 glass manufacturing establishments in the U.S.

135 million ft^2 of enclosed floor space

2,100 buildings

163,258 average ft^2 of enclosed floor space per establishment

Saving as little as \$1.00/ft^2 per year would save a plant \$1 million in six years

Source: *1998 Manufacturing Energy Consumption Survey*. EIA, U.S. DOE

Structural Insulated Panels

Currently used for residential construction, structural insulated panels (SIPs) could be applied for certain types of buildings in a manufacturing complex. SIPs consist of a foam core 4 to 8 inches thick (10.2 to 20.3 cm) with a structural facing on each side. The most common types of facings are drywall and/or structural wood sheathing such as plywood and oriented strand board (OSB). The rigid-insulation core is usually made of one of three plastics: 1) expanded polystyrene (EPS); 2) polyurethane; or 3) polyisocyanurate, a polyurethane derivative. Some manufacturers are also examining ways of using cementitious or fibrous core insulating materials. SIP construction can replace wood or metal stud (a.k.a. "stick") framing in almost any construction setting. The greatest advantage of these panels is they provide superior and uniform insulation and create a more airtight building. This makes the building more comfortable and improves energy use in both the winter and summer.

Using SIPs considerably speeds construction saving time and money without compromising quality. Testing has shown that a wall panel with two, half-inch (1.3 cm) thick OSB skins is nearly three times stronger than a conventional 2 x 4 inch (5.1 x 10.2 cm) stud

wall, even though the SIPs were assembled many times faster than a "stick" framed wall of similar size. They require much less skilled labor too.
The combination of high-insulating value, speed, and construction ease makes SIP walls superior to conventional walls. The solid foam core eliminates air movement within the walls and minimizes thermal bridges through wood studs to make a tightly sealed/easily controlled structure. When installed according to manufacturers' recommendations, SIPs meet all building codes and pass the American Society for Testing and Materials (ASTM) safety standards. Fire investigators have found that in buildings constructed of SIPs the panels held up well. For example, in one structure where the temperature exceeded 1,000 °F (538 °C) in the ceiling areas and 200 °F (93 °C) near the floors, most of the wall panels and much of the ceiling remained intact. An examination of the wall panels revealed that the foam-core had neither melted nor delaminated from the skins. In similar cases, a lack of oxygen seemingly caused the fire to extinguish itself. The air supply in a structural insulated panel building can be quickly consumed in a fire.

Florida Solar Energy Center research showed a 12% to 17% energy savings from using SIP construction. The foam-core wall panels cut air infiltration by 25% compared to conventional stud frame construction. The measured data for residential construction showed 0.21 air changes per hour (ach) compared to 0.27 ach for conventional construction.

Cool Roofs

Analysis of the "heat island" effect in cities has revealed how much heat roofs generate outdoors as well as indoors. Black roofing surfaces in the sun can become more than 70 °F (40 °C) hotter than the most reflective white surfaces. Monitoring of buildings in Sacramento, California, with lightly colored, more reflective roofs found that these buildings used 40% less energy for cooling. Roofs can be retrofit with reflective coatings that will reject more heat. In addition, these coatings can help extend the life of a roof to match that of the building it covers. A few products for coating roofs to be more reflective have been in the market since the 1970s. Today a new generation of products is appearing that is more versatile, has higher performance, and lasts longer when applied to existing roofs. For new construction, designers should specify lighter, more reflective materials for roofs.

Desiccant Cooling and Dehumidification

A desiccant material naturally attracts moisture from gases and liquids. After the desiccant is saturated with moisture adsorbed or collected on its surface, it is regenerated by applying heat to drive out the water. Conventional solid desiccants include silica gel, activated alumina, lithium chloride salt, and molecular sieves. Titanium silicate, a class of material called "1m," and synthetic polymers are new solid desiccant materials designed to be more effective for cooling applications. Liquid desiccants include lithium chloride, lithium bromide, calcium chloride, and triethylene glycol solutions.

When applied in a dehumidifier, the desiccant removes moisture from the air, which releases heat and raises the air temperature. The air is then cooled by evaporative coolers or the cooling coils of a conventional air conditioner. In a stand-alone desiccant cooling system, air is first dried, then cooled by a heat exchanger and a set of evaporative coolers. This system is free of ozone-depleting CFC and HCFC refrigerants. In most systems, a wheel containing desiccants continuously dehumidifies outside air entering the cooling unit. The desiccant is then regenerated by thermal energy supplied by natural gas, waste heat, or a solar thermal energy system. A desiccant system can also supplement conventional air-conditioning systems; the desiccant removes the humidity load while the evaporator of the air conditioner lowers the air temperature.

In certain cooling applications desiccant cooling has an advantage over vapor-compression and absorption because desiccant units don't require ozone-depleting refrigerants, can use natural gas, lower temperature solar thermal energy or waste heat, and they lower peak electric demand. They are particularly effective at treating large humidity loads associated with ventilation air. Controlling high humidity environments can save millions of dollars in unnecessary repairs. Desiccant systems also improve indoor air quality, improve ventilation rates, and remove air pollutants. New building standards (e.g., ASHRAE 62R) that require more outside air for ventilation are also increasing demand for dehumidification. Desiccant systems are a commercial product and excel in niche applications. Future performance improvements will continue to drive down system costs and accelerate integration of desiccants with conventional space-conditioning systems. The number of companies manufacturing solid desiccant dehumidifiers has increased fivefold in the last two decades. The market is expanding because in a number of applications in certain parts of the country, energy costs are high enough that desiccant cooling or dehumidification systems have a simple payback of three to five years, and in some locations, it can be as short as one to two years.

Air-to-Air Heat Exchangers

Air-to-air heat exchangers transfer heat from one air stream to another through contact with a plate or film separating the air streams. Most air-to-air heat exchangers stack ribbed plates so that heated air flows on one side of each plate, while cooler air flows on the other side. The warmer air heats the plate and transfers heat to the air on the cooler side. The heat exchanger has no moving parts and can be located in any relatively clean air streams. Such systems are often specified with exhaust and supply fans to make a balanced Heat Recovery Unit (HRU) to meet ventilation needs without producing drafts or air pressure imbalance. Exchangers are commonly made of inert materials suitable for moist or corrosive environments, and can be designed with easy-to-clean surfaces for use with contaminated air streams. Heat exchangers are modular and can be assembled for air stream capacities up to 80,000 cubic feet per minute (CFM). Because air-to-air heat exchangers work in both directions, they can effectively reduce heating and/or cooling loads.

Air-to-air heat exchangers should be considered whenever air is continuously exhausted and make-up or ventilation air is required for any factory systems. For industrial facilities that require significant air change rates for buildings, laboratories for example, these exchangers can save a significant amount of energy.

Heat transfer from the warm side to the cool side of the exchanger depends on the amount of surface contact area per CFM of air moving through the exchanger. As a practical limit, increasing the amount of surface area past a certain size is not cost effective. The determining factors are material thickness and cost, energy cost, average temperature differences, and pressure losses. Generally, heat transfer efficiencies of 80% are attainable at a material cost of $1.60 to $2.00 per CFM. HRU's complete with fans are closer to $3 per CFM. Many site and application specific factors determine the simple payback for an air-to-air heat exchanger system. In buildings, paybacks commonly range from three to five years.

Lighting

Although lighting efficiency in buildings gained prominent attention in the early 1990s, many industrial facilities still have not modernized. This section will not present detailed information on various options. Instead it will just highlight options to increase the efficiency of electric lighting. Use of sunlight for lighting is discussed separately under "daylighting".

Compact Fluorescent Lights (CFLs)

The U.S. Department of Energy stimulated the market for sub-compact fluorescent light bulbs by working with four manufacturers to create a program that offered low prices direct from the manufacturer to volume buyers. CFLs use much less energy than incandescent bulbs and need replacing far less often, making them a cost-effective choice. CFLs have also been used effectively to replace halogen lights in torchieres. Although early CFLs had a stark light, the color rendering of newer CFLs is equal to or superior to incandescent light bulbs, producing full-spectrum or softer yellow lighting. When electricity averages 8 cents per kilowatt-hour, a 20-watt CFL that replaces a 75-watt incandescent bulb will save $20 in 12 months if the fixture is on 12 hours per day. They also last 8 to 10 times longer than incandescent bulbs, which saves labor needed to replace bulbs, and they generate much less heat, thereby lowering cooling loads.

Sulfur Lamps

A result of DOE-supported technology development, sulfur lamps are bright, long-lasting, energy-efficient light sources that are effective in commercial and industrial buildings. The sulfur lamp's brightness and longevity make it ideal for large industrial facilities similar to aircraft hangars. The lamp time to failure is much longer than other conventional lighting technologies, since sulfur lamps do not have filaments or electrodes to burn out–the major cause of failure in other lamps.

A sulfur lamp uses less than 20% of the energy of a traditional incandescent lamp of equivalent brightness, and approximately 75% of the energy of metal halide high-intensity discharge lamps that would serve the same function. While the strength of light from a conventional source can weaken over time, the output from a sulfur lamp remains constant over its life. As a result, there is no need to compensate for a drop off in lumen output by using an excessively powerful lamp. It produces a sunlight-quality light source, with very low heat, virtually no ultraviolet emissions, and a full color spectrum. Color rendition is particularly important in many manufacturing environments.

Light Emitting Diodes (LEDs)

LEDs are low-energy light sources that can save energy in such applications as flat-panel displays, exit signs, and traffic lights. They are now entering the market for niche lighting applications and come in a variety of colors, including white. The prices are still much higher than ordinary light bulbs; however, an LED uses one-tenth the power of an incandescent light bulb and one-third the power of a fluorescent light bulb. Furthermore, an LED has a projected life of 100,000 hours (100 times longer than an incandescent bulb) and can operate in a wide temperature range. They can be ideal for task lighting and for illuminating areas hard to reach because an LED can run 24 hours per day for 11 years without needing to be replaced.

Electronic Ballasts

Ballasts are an essential part of fluorescent lamps, transforming standard voltages into the voltage needed for the lamp. When replacing standard fluorescents with energy-efficient lamps, it's necessary to replace the existing ballasts. Magnetic ballasts are now being phased out in favor of more energy-efficient electronic ballasts, which can improve fluorescent light fixture output and reduce electricity consumption 20 to 25%. Electronic ballasts operate 75% more quietly than conventional ballasts, eliminating the familiar flicker and hum of older fluorescent lights. Simple payback periods on these improvements can be as short as one to two years.

Reflectors

Reflectors can be installed behind fluorescent lamps in their fixtures to increase the amount of light directed to the area being illuminated. Improved reflectors for fluorescent fixtures can light an area better using fewer lamps. Reflectors can increase the effectiveness of a fluorescent lighting fixture by about 10% in some situations by directing more light onto the work space. Reflectors installed with energy-efficient fluorescent lamps and electronic ballasts can reduce lighting energy costs by as much as 70%. Reflectors do not have to be limited to fluorescent light bulbs.

Fiber Optics

Fiber optics have the advantage of carrying light around bends and corners with little loss in brightness. They can be used to distribute light throughout a building from a central lighting source.

Task Lighting

Lighting is more efficient when it is applied directly to a task (for instance, a bright light over a desk) rather than illuminating the entire room at the same lighting level.

Lighting Controls

Controls such as photosensors, occupancy sensors, and timers can save energy by turning lights off when they are not needed. This approach is particularly effective for security lighting and lighting in infrequently used rooms. Dimmers also save energy by allowing building occupants to adjust the light output to suit their needs.

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Daylighting for Industrial Buildings

- Windows
- Atriums
- Skylights
- Dome Structures
- Clerestories
- Roof Monitors
- Light Shelves
- Light Pipes

Daylighting is the use of direct, diffuse, or reflected sunlight to provide full or supplemental lighting for building or factory interiors. Artificial lighting accounts for as much as 40% to 50% of the energy consumption in many commercial and institutional buildings, and 10% to 20% of energy consumption in industry. When combined with energy-efficient lighting in office buildings, daylighting can lower the the amount of electric power needed for typical lighting from 2.2 W/ft^2 (23.7 W/m^2) to 0.88 W/ft^2 (9.5 W/m^2) without reducing foot-candles at the work surface. This is a 60% reduction in energy cost for lighting. Daylighting can equally reduce artificial lighting requirements and energy costs in many industrial buildings.

Architectural techniques to transmit daylight into a factory include conventional windows, atriums, skylights, dome structures, clerestories, and roof monitors. The most common means of daylighting is a window, and those with a higher head (top) allow daylight to penetrate further into a room. An atrium is an interior courtyard covered with glazing. Rooms adjoining the atrium benefit from daylight entering through the glazed roof. A skylight is a transparent panel set into a roof that allows direct and diffuse sunlight into the building. If a skylight has a convex glazing, it is called a dome structure. Clerestories are windowed vertical wall sections usually installed close to the roof line to admit daylight. A roof monitor is a raised, often triangular shaped, section of a roof with at least one glazed surface. Clerestories and monitors can provide large quantities of reflected and diffuse light, especially when located above and in front of a light colored wall. When facing south, the monitor glazing can also provide solar space heating. Coatings or films on windows and skylights are employed to control heat transmission into and out of the building space. Recent development of new films and electrochromic "smart windows" that change tint in response to light intensity, heat, or electric current, are able to balance seasonal heating and cooling requirements when employed in a daylighting strategy.

A challenge in daylighting design is to provide illumination in areas where it is most needed, such as for northern exposures, internal cavities, and ground levels of multi-story buildings. The solution is to install design techniques that redistribute sunlight by diffusion or reflection. Fixed and/or movable exterior baffles or louvers running horizontally or vertically across windows will reflect and diffuse sunlight. Mechanical devices are another approach to focus and direct daylight into building interiors. Light pipes are fixed tubes that direct and transmit light to areas where it is needed by way of internal reflective surfaces that direct daylight entering the tube down or horizontally into building interiors. Able to provide high-quality light with little heat or glare, light pipes are useful in areas that are difficult to light, can send light to the lower floors of multi-story buildings, and meet special lighting requirements in laboratories, quality control, and assembly work areas.

Skylight systems can employ a roof-mounted reflector called a heliostat that moves to track the sun and focus light into a second stationary mirror. A heliostat-based system can use light sensors, pulse motors, and a microprocessor or a computer to track the sun. The second mirror directs the concentrated beam to light pipes or down through an atrium or skylight. Other mirrors may be placed on each floor of an atrium to direct a portion of the beam onto a ceiling section. Inexpensive skylight tracking systems (less than $1,000 each, installed) are gaining acceptance for the lighting of warehouses and other single-floor buildings in areas with many cloudless days. These utilize tracking blinds or reflectors mounted on the roof to reflect the maximum amount of light through a prismatic skylight, which spreads the light over the area below.

Another type of mechanical system employs a roof mounted Fresnel lens that tracks the brightest portion of the sky and concentrates and directs daylight to a secondary Fresnel lens. The primary Fresnel lens focuses daylight through a small glazing area while the secondary lens directs light inward to illuminate building space. Fresnel lenses can also be used to concentrate light into optic cables. This system separates light to exclude ultraviolet (UV) and infrared (IR) light from the visible light beam used for illumination. Two types of fiber-optic cables are used in such systems. Flexible light directing fiber optic cables transmit light by total internal reflection. Good quality fibers lose as little as 0.1% of captured daylight per foot of length. Low quality fibers lose over 1% per foot of length. Light dispersing fiber optic cables–the other type of optical fiber–accept light from a transmitting cable and distribute it to the space. By responding to daily and seasonal changes of the sun, these types of mechanical tracking systems offer the greatest control for daylighting.

A must for any daylighting system is installation of lighting controls for the conventional electric light fixtures. Without them, no energy savings will occur unless occupants are aware and religiously turn off unnecessary lights. A variety of control options exist, including on/off switching, dimmers, and multi-level cut-off systems. In sum, effective daylighting design requires balancing of the elements of artificial lighting, solar heat gain, heat loss through glazing, and internal sources of heat gain. A proper system will be integrated with electric lighting, heating, cooling, and ventilation systems as well as occupant task and movement patterns.

Economics

If a factory work area were lit at 2 watts per square foot over a period of 4,000 hours, the total energy required would amount to 8,000 watt hours per square foot. At $0.07 per kilowatt-hour, this amounts to $0.62 to light each square foot per year of a factory running two shifts per day. If a daylighting system were employed to cut the power demand to one watt per square foot, the simple electric power savings would amount to $0.31 per square foot per year. This simplified saving estimate for a 50,000-square foot production facility would amount to $15,500 per year.

Actual savings would be larger because light fixtures would be run fewer hours, saving on bulb or tube replacement and maintenance labor to replace them. The electric load for lighting during daylight hours would be cut enough to save on peak power pricing and could also cut demand charges. In addition, a daylighting system in buildings may also reduce cooling costs because daylight produces less heat per unit of illumination than artificial lights. If daylighting were incorporated into a passive solar heating system, the sunlight would also provide supplemental building heat during the winter months. Finally, if a new building has these features incorporated into the design, the initial capital cost for HVAC equipment can be cut because the heating, ventilation and cooling equipment could be downsized.

Although difficult to quantify as cost-saving benefits, daylighting generally increases occupant satisfaction by providing a healthier, more pleasant environment. The human eye adapts easily to daylight, and the glazed (clear or translucent panels of plastic or glass) surfaces needed for daylighting give the occupants a sense of contact with the outdoors. Various studies suggest that daylighting increases worker productivity, enhances student learning and health, and contributes to higher sales in retail stores. Daylighting may also reduce the loss of worker productivity during power failures and studies have credited daylighting retrofits with a reduction in worker absenteeism.

Commercial buildings designed with daylighting and passive solar for heating, ventilation, and cooling load control can add anywhere from 3% to 15% to new building construction costs over conventional construction. Such buildings have significant savings, often requiring 60% less energy than conventionally designed and fabricated structures. Daylighting alone can often be added to buildings at no additional cost.

Costco, a major discount retailer, has incorporated daylighting into its stores and in one of its dry goods distribution centers, which would be similar to warehouse types of factory buildings. The Costco center in Mira Loma, California, is 653,000 square feet and has 1,050 5x6-foot skylights covering 4.8% of the rooftop. There are 1,640 metal halide luminaires (HID) that operate in three daylit zones; the HIDs are shut off when adequate light is available from the skylights. Pacific Gas & Electric Company has projected that annual energy savings for this new facility should amount to 2.5 kWh per square foot, which at current electric rates would be $150,000 per year. For smaller buildings, with higher lighting requirements like a 150,000-square foot Costco store that maintains 50 to 65 foot-candles of light, the savings should amount to 1.5 kWh per square foot per year, or $23,000. Skylights and lighting controls connected to an energy management system controlled centrally are standard in new Costco buildings.

Solar Energy Technologies

SOLAR THERMAL - Make heat, cold air, steam, and electricity

Flat Plates
- Air
- Liquid
- Heat pipe

Concentrators
- Troughs
- Dishes
- Central receiver

DAYLIGHTING - Offset/reduce artificial lighting needs

- Fixed
- Light Pipe
- Heliostat

PHOTOVOLTAICS - Make electricity

Flat Plates
- Fixed
- Tracking

Concentrators
- Fresnel
- Mirror

Environment
Structures designed with solar daylighting or passive solar heating, ventilation, and cooling control are low energy consumers and have many environmental pluses. The construction materials used are common and no special requirements exist with regard to handling or disposing of them. For a daylighting system with a mechanical tracker, the only energy consumption for the system would be for a small motor and an electronic control.

Market
Daylighting is a commercial "product." For non-mechanical systems the main components are conventional building products, or new films and coatings applied to glazings. For mechanical systems, a small number of manufacturers produce the tracking and mirror or Fresnel lens systems, and light pipes. Daylighting systems have to be designed; consequently, delivery of the "product" is in the hands of architects and engineering companies or specialists in this field. Thousands of daylit buildings exist, and the track record for performance is well documented by the Department of Energy and many state energy programs.

Technology Outlook
The technology for daylighting is well advanced, and sophisticated computer tools are ready to help designers create well performing systems that are highly cost-effective. Design is important because a key concern about daylighting relates to dependence on unpredictable weather and availability of sunlight. Factors that effect the availability of adequate daylighting include the position and intensity of the sun, cloud cover, and shading by nearby hills, vegetation, and buildings. The most successful daylighting projects consider the purpose and indirect costs of the lighting, as well as the direct costs. If not properly designed, the glazed areas that allow daylight into a building may also contribute to heat losses in the winter and undesirable heat gain in the summer. These additional heating and cooling costs may offset savings from reduced lighting costs. While more advances will be forthcoming for mechanical systems, the technology available now performs reliably.

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Technologies from the Office of Energy Efficiency and Renewable Energy Inventions and Innovation Program

The following technologies received development funding support from the U.S. Department of Energy Inventions and Innovation Program and have been commercialized by the inventors.

Aluminum Roofing System

The membrane of a typical built-up roof consists of several layers of bitumen and asphalt-impregnated felt; typically, five to seven layers may be used. Accelerating decomposition and embrittlement of composition bitumens due to the high temperatures a black roof generates are likely to reduce the service life of such an asphalt roof. A light-colored roof coating that lowers heat gain will help reduce the intensity of such degradation.

Through a grant from DOE's Inventions and Innovation Program, Transmet Corporation developed aluminum roofing chips that exhibit superior solar reflectance compared with competing roofing systems. The chips are tiny aluminum particles made in a proprietary process that rapidly solidifies small streams of liquid metal. When air-sprayed at a rate of 3 to 4 pounds/square foot onto the surface of the asphalt flood coat, the chips form a highly reflective roof surface. The chips weigh only 3 to 4 pounds/100 square feet compared with stone aggregate coverings of 300 pounds/100 square feet.

Economics

Covering one small commercial roof with a surface area of 10,000 square feet would result in annual energy savings of 79 million Btu. The chips also reduce maintenance costs by eliminating the need for recoating. The savings can amount to as much as $10 per 100 square feet of treated roof compared to untreated asphalt.

Environmental

The chips greatly extend roof life by reflecting 77% of incoming infrared solar energy and 75% of ultraviolet energy.

Accelerated aging test have shown negligible deterioration of the reflectivity and emissivity properties of aluminum chip surfaces. Visual inspection, likewise, usually reveals no significant roof deterioration after six to eight years of life.

Market

Since its introduction in 1984, this invention has been used on more than 35 million square feet of roofing. Although most of the installations have been to roofs in the United States, the technology has also been used on roofs in Singapore, Bahrain, and the United Kingdom.

Technology Outlook

Factory applications of aluminum chips to rolled roofing materials are gaining acceptance.

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PowerGuard®

With the help of a grant from the U.S. Department of Energy Inventions and Innovation Program, PowerLight Corporation developed its PowerGuard® roofing system that offers insulation, shading, roof protection, and solar power generation in a single roofing panel. The roofing panel includes a photovoltaic module mounted on a 3-inch-thick styrofoam board coated with a proprietary, cementitious coating. Designed specifically for flat or very-low sloped commercial and industrial buildings, the roofing panel works as a retrofit over existing roofs, as a new roof with new construction, and for re-roofing. The system can be tailored to capacities of 1 kW or greater and allows easy expansion.

The PowerGuard system can provide up to 10 watts per square foot of roof space, which meets the electrical load of most large businesses during warm weather. The PowerGuard system reduces the building air conditioning load because the polystyrene panels shade the roof surface from the sun and provide R-10 insulation above the roof surface.

Economics

The lightweight PowerGuard system is designed to survive severe weather conditions. It also protects the roof membrane from harsh UV rays and thermal degradation for up to 30 years, approximately doubling the life of the roof.

In places where utility electric rate billing is based on time of day and extreme peak demand charges are in effect, PowerGuard shaving of electrical demand during peak time rates will significantly lower the system's payback time.

Environmental

PowerGuard feeds clean AC power into the building. A 200-kW system saves approximately 22,000 barrels of oil equivalent over its life, reducing CO_2 emissions by 12,000 tons.

Market

PowerLight Corporation boasts over $35 million in complete renewable energy products. The company mainly seeks installations over 30 kilowatts of photovoltaic peak capacity.

Technology Outlook

PowerLight Corporation continues to grow at approximately 300% each year.

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WhiteCap®

WhiteCap is a unique roofing/cooling system that not only provides protection from outdoor conditions but also increases cooling energy savings. The unique innovation provides commercial one-story flat-roofed building owners the ability to double a flat roof's life expectancy and cut cooling loads by at least 50%.

With the help of a grant from the U.S. Department of Energy Inventions and Innovation Program, Roof Science Corporation developed this innovative roofing system. The system uses a single-ply roof membrane placed on a "dead level" roof deck. Instead of adhesive, mechanical fasteners, or gravel ballast, the WhiteCap system uses three to four inches of water, which is thermally decoupled from the building. Unlike conventional roof concepts, the WhiteCap system places the roof insulation above, rather than below the roof membrane. The WhiteCap roof typically outlasts exposed membrane roofs, because the membrane is protected from solar heat gains, temperature extremes, and physical damage.

The floating insulation consists of four-inch thick interlocking four- by eight-foot extruded polystyrene insulation panels, which are coated with a white fire-resistant material that reflects the sunlight and provides the system's thermal insulation. The water circulation system consists of a pump, filter, controller, piping system, and spray heads. This system maintains the desired water level at night, sprays the water uniformly over the floating insulation panels where absorbed heat is rejected into the atmosphere. During the daytime, the volume of cooled waters acts as a heat sink by absorbing the building's heat load, thereby reducing energy consumption for mechanical cooling.

The company also designs and installs WhiteCap systems that spray cool water on the roof at night, then collect the chilled water at roof drains for storage in a water tank on or below the ground. This configuration also provides substantial energy savings without requiring water storage on the roof.

Economics

In studies of existing WhiteCap installations in commercial buildings, WhiteCap systems have provided between 30% and 60% of the building's annual cooling load.

Environment

Most of the degradation to a building roof surface occurs because of weathering caused by large daily temperature variations and by ultraviolet radiation from the sun. However, WhiteCap roof systems protect the roof with a water layer and insulation panels and little degradation to the actual roof surface is expected over time.

Market

The primary market for this invention is new commercial/industrial single-story flat roofed buildings where large amounts of electricity are used for mechanical cooling. This market can further be expanded in the retrofit market.

Technology Outlook

WhiteCap must overcome the marketing hurdle of putting water on the roof. The WhiteCap system may face resistance by architects, builders, roofing contractors, and building engineers who will question the system's reliability and durability, excessive water use, and increased structural costs when water is place at "dead level" on the roof.

Addressing this concern, the inventor has conducted studies showing that the WhiteCap system modestly increases structural costs and uses no more water than conventional cooling towers and swamp coolers.

The addition of WhiteCap systems, which collect the chilled water at roof drains for storage in water tanks on or below the ground, may also help WhiteCap prevail.

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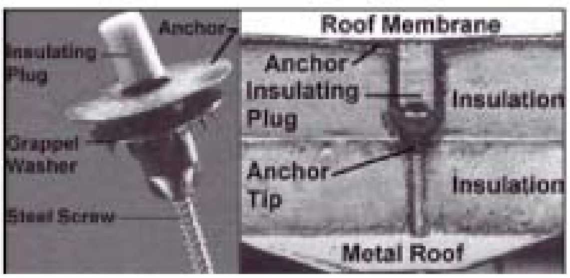
RR-1 Insulating Screw Cap

Roofing systems found on industrial and commercial buildings continue to show impressive strides in their performance and durability. Fasteners play an essential role by keeping many of these roofs intact through joining of pieces or multiple layers. However, the combination of newer roofing materials, known as single-ply membranes, with conventional metal fasteners leads to increased heat loss. This loss occurs because the metal screw and plate of the fastener are only minimally insulated from the surroundings and conductive heat flow occurs through the thermal bridge created by the metal fastener.



The RR-1 Insulated Screw Cap Assembly, developed and patented by The Romine Company, is a simple but effective solution to heat loss and back-out problems found with many conventional fasteners. This improved fastener consists of an injection-molded fiberglass reinforced nylon anchor, soft insulating plug, and optional grappel washer. It is simple to install and incredibly strong.

The key advantage of the RR-1 is that the metal screw portion of the fastener is embedded at least one inch into the insulation board, reducing the rate of heat transfer and the potential for corrosion. A plug of foam is inserted in the cavity created and acts as an insulator as well as providing an extremely smooth surface without the bumps created by typical screw heads. No predrilling is needed. The simple flush mount requires less torque and time to screw in.

In tests conducted on wind uplift, the strength of the RR-1 Insulating Fastener proved to be greater than the holding power of the metal decking.

Economics

The RR-1 Insulated Screw Cap can save significant amounts of energy for heating and cooling of buildings. The number of premature roof failures arising from corrosion would also be reduced.

Environmental

Dr. Michael McCabe, a scientist with the National Institute of Standards and Technology, has estimated that after 10 years on the market, the RR-1 would save an equivalent of 210,000 barrels of oil per year just in the reduced heating and cooling of buildings.

Market

The greatest potential for the RR-1 assembly is in single-ply (flexible) membrane systems, which have gained an increased market share.

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High-Efficiency Direct-Contact Water Heater

Through a grant from the U.S. Department of Energy Inventions and Innovation Program, Kemco Systems, Inc., created a near-ideal heat transfer system for commercial and industrial water-heating systems. Kemco's water-heating system employs a water-cooled burner sleeve and combustion zone to extract all possible energy from natural gas combustion by bringing water into direct contact with a submerged-flame, jet-type burner. The incoming water is directed through the stainless steel walls of the combustion zone. The balance of water to be heated is sprayed into the top of the vessel, where it absorbs heat from the exiting flue gases. The spray falls directly into the open flame, collects in the bottom of the tank, then is pumped to the storage tank or load. This system captures the related latent heat of vaporization, which can represent as much as 13% of the total heat. A Kemco boiler is 40% more efficient than a typical water heating system that has a 70% conversion efficiency.

Economics

A Kemco 15 million Btu/hour unit that replaced steam boilers at the Ford Motor Company's automotive assembly plant in Edison, New Jersey, saves approximately $400,000 per year.

The direct-contact hot water heater also saves costs by eliminating the need to buy insurance for a high-pressure system, employ a licensed boiler operator, conduct annual inspections, and buy boiler treatments and chemicals.

The total cumulative energy savings from Kemco systems are over 340 trillion Btu through 2000. Cumulative savings for avoided fuel purchases total over $1 billion in inflation-adjusted 1999 dollars.

Kemco estimates a 12- to 24-month payback period for its direct-contact water heater based on reduced fuel consumption.

Environmental

Direct-flame heating significantly lowers oxygen content of the heated water, reducing corrosive properties of the heated water and reducing air emissions from gas combustion.

The cumulative reduction in CO_2 emissions is estimated to be almost 20 million tons.

Market

Kemco Systems, Inc., is the market leader for direct-contact water heating. The Kemco system is available in 1.2 to 25 million Btu/hour capacities and provides flow rates from 10 to 500 gallons/minute.

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Solar Skylite Water Heater

With a grant from the U.S. Department of Energy's Inventions and Innovation Program, American Solar Network, Ltd., developed an attractive, easier to install solar water heating system with a skylight appearance. An updated model is marketed by SolarRoofs.com, a division of ACR Solar International Corporation.

Named the Fireball 2001®, the system's rooftop solar collectors weigh less than 38 pounds, have a low profile, are self balancing, and have a 150 mph wind rating. The collector uses a high-performance copper absorber coated for low emissivity and high absorption. The glazing, or "window," on the collector takes the brunt of the sun's rays and traps them inside to create a greenhouse effect similar to what is experienced when getting into a car with its windows closed on a sunny summer day.

Solar-heated water from the collector is circulated to the existing hot water heater using copper tubing. Various models offer open- and closed-loop configurations as well as PV power for the pump.

Economics

Solar water heaters are by far the lowest cost source of solar power. Annual energy savings range from 15% to 35% depending on the situation. It would take a 1-kW solar PV system to produce the same thermal power as one 20-sq. ft. Fireball collector which can be installed for under $1,800 or under $1,200 in volume.

Environmental

Solar water heaters are healthier for the environment because solar energy avoids the harmful emissions of electrical energy generation. Enough solar water heaters could reduce California's energy consumption by 2%, which would significantly reduce pollution.

Market

In states with high insolation (lots of sunshine) and high electricity prices, solar water heating has established a solid and growing market presence.

Technology Outlook

Based on initial commercial success of the technology and subsequent improvements, the inventor has created a series of solar water heating projects for swimming pools and residential and commercial buildings.

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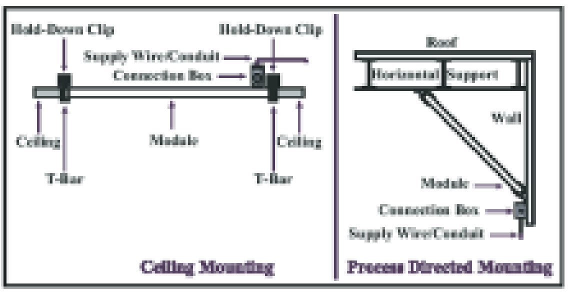
Radiant Heating Panels

Under a grant from U.S. Department of Energy Inventions and Innovation Program, Solid State Heating Corporation, Inc., commercialized a novel radiant heating panel, the Enerjoy.

The panel contains a patented heating element consisting of electrically conductive material laminated between two layers of polyester film. It contains two electrodes that deliver electricity to the conductive surface. A 1-inch thick, 6-pound density fiberglass board gives the panel strength and rigidity while serving as an R-6 insulating thermal barrier. Unique construction minimizes heat loss from the panel back and permits direct mounting to ceiling or wall surfaces without expensive and unsightly mounting brackets.



The radiant heater has a long life and requires no mechanical heat delivery system. Radiant heating systems emit infrared radiation that travels through the air and directly warms objects, whether people, furnishings, or walls. A radiant heating system uses electricity, but does not have a fan to move air over resistance coils in order to heat the space.

Radiant heating allows a building designer to lower the space-heating requirement for the whole structure and eliminate the need to heat unoccupied areas. Rooms can be maintained at temperatures 6 to 8 °F cooler while maintaining the same comfort level for occupants. When the unit is energized, comfort is felt immediately even though room temperature has been lowered to conserve energy. Radiant heating panels can easily be incorporated in buildings using daylighting.

Economics

Quick response and immediate heating raises comfort level while ambient air temperature can be 6 to 8 °F cooler than with other heating systems. Radiant heating panels easily accommodate zonal heating systems that eliminate heating of unoccupied spaces in structures and can lower the cost of heating by 52% compared with baseboard electric-resistance systems.

Because the flat panels integrate into walls or ceilings, installation costs are low. This system requires no maintenance.

Environmental

Energjoy provides clean, silent, draft free, and non-allergenic heat, and it neither produces static electricity nor drys the air. It is suitable for clean rooms since it can eliminate the need for forced-air or hydronic heating systems with associated contaminates. It also increases safety in locations with combustible vapors.

Market

The Enerjoy is available in two standard models as well as custom sizes. Enerjoy 1 is a low-watt density model for residences and small businesses. Enerjoy 2 is a high-watt density model for commercial and industrial installations, including high-humidity and hazardous locations.

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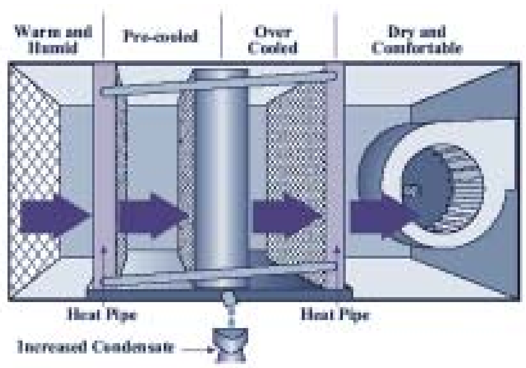
High-Efficiency Dehumidifier

Heat Pipe Technology, Inc., (HPT, Inc.) originally researched a heat pipe technology for application in NASA's space programs. Through a grant from the U.S. Department of Energy Inventions and Innovation Program, HPT, Inc., revised the technology for several commercial uses.



The HPT, Inc., system can fit any air-conditioning system. It is built in two sections; one section resides in the warm return airstream and the other in the cold supply airstream. The heat pipe operates automatically whenever the air-conditioning system runs. The first section absorbs heat from the return air before it reaches the cooling coil, which lowers the operating temperature of the evaporator coil, which increases the moisture removal capacity of the system by 50% to 100%. This pre-cooling effect lowers the cooling load on the compressor, which can be downsized in new or retrofit installations. The heat absorbed by the first section of the heat pipe is transferred to the second section to reheat the supply air for humidity control.

Economics

Less humid indoor air feels more comfortable, so cooling temperature thermostat settings can be higher to save energy (generally, each 1 °F rise in the thermostat setting results in a 7% saving in electricity costs).

The system requires 50% less energy than electric reheat and about 25% less energy than air conditioning systems using other types of reheat.

Environmental

Installing a heat pipe heat transfer unit can increase the dehumidifying capacity of a cooling system by as much as 91%, which improves health conditions such as arthritis and helps prevent the growth of mold, mildew, fungus, and dust mites. Achieving a higher level of dehumidification can help cure "sick building" problems with conditioned fresh air.

The heat pipe eliminates the need for reheat or desiccant systems and operates with no mechanical or electrical input.

Market

This technology was first commercialized in 1991 and has since been installed in over 6,500 applications.

Technology Outlook

Heat Pipe Technology, Inc., continues to research and make innovative developments in heat pipe technology.

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SOLARWALL®

Conserval Systems, Inc., developed an innovative yet simple air-preheating system, the SOLARWALL® system, that uses solar energy to increase the temperature of incoming ventilation and makeup air.

The dark-colored and perforated facade is installed on the south-facing wall of the building. Sunlight heats the facade. The combustion system draws outside air into the building through the holes in the facade and through the space between the facade and the building, heating that air in the process. At the same time the facade captures heat loss through the building wall and shields the building from solar gain when heating is not needed.

An Inventions and Innovation grant, along with additional funding provided by the Department of Energy's Office of Power Technologies and the Office of Building Technology State and Community Programs, allowed Conserval to improve the efficiency of SOLARWALL systems substantially, to develop design tools to predict and optimize energy savings, and to verify that the system could be installed on roofs for space heating and crop drying. Efficiency gains were made with a header duct, optimizing hole size/spacing, air flow rates, and coatings. This system can also be used with thermal storage. For example, as glass plants convert to oxy-fuel, the regenerators are normally removed. This system could store thermal energy for nighttime use in air combustion forehearths to reduce the outside air temperature variation, which impacts productivity.

The largest U.S. SOLARWALL installation is located at a Fort Carson helicopter hanger, where 7,800 square feet of SOLARWALL save 3.3 billion Btu of natural gas.

Economics

SOLARWALL has an operating efficiency up to 75% and can raise air temperature by as much as 61 °F to 104 °F, depending on flow rate. An industrial installation saves $10 to $60 in energy costs per square meter of wall coverage.

Simple payback ranges from 0 to 3 years for new construction and 3 to 8 years for most retrofit applications. SOLARWALL installations are eligible for federal solar energy tax credits and a 5-year accelerated depreciation schedule.

Environmental

SOLARWALL reduces greenhouse gas emissions by using renewable solar energy instead of fossil fuel for ventilation heating.

Cumulative energy savings through the year 2000 have surpassed 36 billion Btu. The associated reduction in CO_2 emissions is estimated to be 2,200 tons, and avoided energy purchases total $230,000.

Market

Conserval's SOLARWALL heating can cost-effectively save energy wherever large amounts of outside air must be heated. It is ideal for manufacturing plants and other commercial and institutional buildings with large air heating or combustion requirements. Combustion air heating uses include central-heating plants and industrial furnaces.

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IceBear: Thermal Energy Storage for the Small Packaged Thermal Air-Conditioning Unit

The IceBear is an ice storage air-conditioning module engineered to upgrade existing air-conditioning equipment into Thermal Energy Storage (TES) Systems, and is designed for use with a 5- to 20-ton capacity rooftop or split system air-conditioning system.

The IceBear and an air-cooled condensing unit operate during off-peak hours to store energy as ice. During peak daytime cooling, the IceBear functions as the condenser, circulating ice-condensed refrigerant with a 100-watt refrigerant pump.

Capable of several different installation configurations, the IceBear can be used to expand an air conditioner's capacity, or perform two different energy conservation functions: load-shifting and load-leveling. In load-leveling applications the IceBear achieves a 30% energy savings when compared to standard rooftop air conditioners.

In load-shifting applications the IceBear shifts energy demand from peak energy periods to off-peak periods.

The IceBear consists of a heat exchanger made of helical copper coils placed inside an insulated polyethylene storage tank, an air pump to enhance the heat exchanger's heat transfer rate, a refrigerant pump, and an air-cooled condensing unit. To provide air conditioning, the IceBear pumps refrigerant to an evaporator coil in an air handler.

By using the condensing unit to produce ice during the night and the refrigerant pump to supply condensed liquid refrigerant to the evaporator coil during the day, the IceBear may effectively be used in either transferring the majority of load requirements to nighttime hours or in leveling energy loads. In both of these applications, the IceBear also reduces humidity levels, which aids in meeting indoor air quality standards.

The IceBear is designed to meet retrofit, replacement, and new construction requirements in light commercial air conditioning and industrial process cooling.

Economics

Load-shifting provides the greatest demand reduction, typically as much as 90%. Load-leveling, sometimes called partial storage, typically provides 40% demand reduction during peak cooling periods and up to 90% during months with small cooling loads.

Environmental

The IceBear's ability to reduce level will assist in meeting acceptable indoor air- quality standards.

Market

Market potential for the IceBear appears to be promising for both load-leveling and load-shifting applications due to the increased use of real-time pricing.

The IceBear can be used with 5- to 20 ton capacity roof-top or split system air conditioning systems. Applications of the IceBear will include new and retrofit installations.

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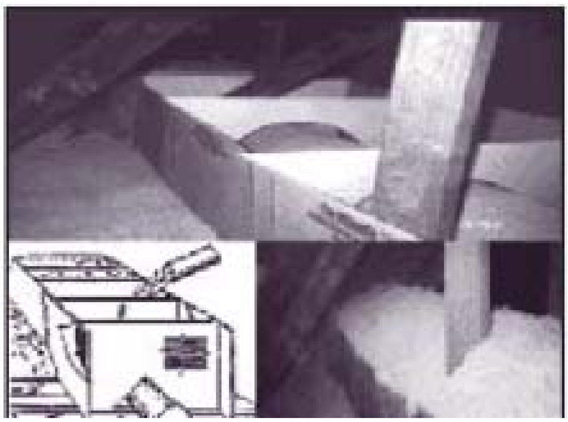
Insulation Containment Apparatus (The Ultimate "R")

Currently, the most common method of adding insulation to heating, ventilating, and air conditioning (HVAC) ducts is to wrap them with a blanket or batt of insulation. Another less common procedure is to adhere insulation board to the ducts and tape the joints. Research shows that the above methods appear somewhat limited in the thickness of insulation that can be added, but are acceptable for suspended ducts which are usually found above drop ceilings, and in crawl spaces. Furthermore, insulation blankets, batts, or boards are often placed over the tops and sides of existing ducts, with usually no attempt made to seal the insulation joints, or to effectively snug them to the air duct's outside surface. This method raises the issue of insulating effectiveness when insulation is installed in this manner.



A new method of adding insulation to HVAC ducts in attics was developed by Theron Crall, Jr., with the aid of a grant from the U.S. Department of Energy Inventions and Innovation Program. This invention, called "The Ultimate R," is a new method of adding up to R-38 of additional insulation to HVAC ducts installed in unconditioned attic space of either existing (retrofit) or new construction applications. To install this invention, the ducts must be very close to level and located on the enclosed space floor. The system consists of a series of moisture resistant light-weight corrugated cardboard cells that can be placed around existing un-insulated or inadequately insulated HVAC ducts. The cells interlock so they form a continuous "trough" that is filled with loose, fibrous, or cellular insulation. These cells act as containment devices to keep the loose-fill insulation packed around the top and sides of the ducts for uniform thickness and maximized thermal insulation.

The Ultimate R addresses both duct leakage and conductive heat loss by requiring that the duct air leaks be sealed before the insulation is installed and providing full R-38 insulation uniformly around the ducts. The Ultimate R is a simple method of insulating duct work that can be installed by "professional" insulators as well as "do-it-yourselfers."

Economics

A study was conducted in which three homes were retrofit with the Ultimate R duct insulating system. The average annual energy savings, accounting for heating only, amounted to 10.3 Mbtu.

The cost of installing the Ultimate R in a typical 1,400-square foot single-story home will be $200-$400, with estimated payback ranging from 1.3 to 2.6 years.

Market

Sales through 2000 have exceeded 2,000 linear feet.

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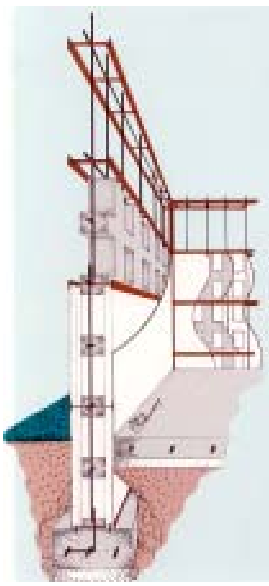
GibBAR-Wall™ System

Insulating the walls of U.S. commercial and industrial buildings could conserve up to 30% in energy costs–energy equivalent to several hundred million barrels of oil annually.



Through a grant from the U.S. Department of Energy Inventions and Innovation Program, Industrial Foam Products developed an innovative means of constructing poured-concrete walls, the GibBAR-Wall™ System, that creates a lattice monolithic reinforced concrete wall with prefabricated permanent polystyrene wall forms and a steel channel lock-in-grid system.

The polystyrene forms are placed within a framework of steel braces and concrete is poured into the open spaces to create the wall. The size and thickness of the forms can be varied according to need, but typically, the system provides wall sections 10 feet wide and 32 feet high with R-19 insulation properties.

The forms and framing displace up to 30% of the concrete used in conventional construction. Despite this reduced volume of concrete, the GibBAR-Wall™ System still offers greater wall strength plus cost-effective insulation.

Economics

Buildings using the GibBAR-Wall System have documented energy savings between 50 and 75%. Higher insulation value also permits HVAC system downsizing, lowering initial construction costs as well as operating costs.

The estimated cost of erecting insulated building walls using the GibBAR-Wall System is about $9.00 per square foot, as compared to $10.00-$12.00 per square foot for conventional methods.

Environmental

The engineering of the GibBAR-Wall System makes it particularly suitable for structures in earthquake-prone areas. It meets national fire codes and standards for earthquake-resistant buildings.

Market

There are two GibBAR-Wall Systems currently in the market: the POUR-IN-PLACE System, and the CAST-TILT System.

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A Dual-Fuel Conversion System for High-Output, Medium-Speed Diesel Engines

Diesel engines have been used for decades in industrial power generation, cogeneration power systems, locomotives, marine applications, and other engine markets. However, as tougher environmental standards are being enacted throughout industry, users of diesel engines are looking for ways to lower emissions without reducing engine power.

Dual-fuel systems, engines that operate on more than one fuel source, are gaining popularity because they have the potential to reduce the amount of diesel fuel used. Until recently, adding a dual-fuel system was impractical because of the cost of replacing the original engine and the loss of power traditionally associated with these replacement systems.

With assistance from the U.S. Department of Energy's Inventions and Innovation Program, Energy Conversions, Inc. (ECI), has invented a dual-fuel conversion system that easily converts diesel engines into diesel-natural gas engines, eliminating the need for companies to replace their diesel engines with natural gas engines. ECI dual-fuel engine systems consist of specifically engineered pistons and heads, patented gas injectors, a supplemental cooling system, and ECI-engineered controls. This system enables converted engines to operate on 90% natural gas while maintaining engine efficiency and fully rated horsepower. Dual-fuel operation is completely automated, requiring no user input. If a function falls out of normal operational limits, full diesel operation is activated instantly with no interruption of service.

Economics

An ECI conversion systems is currently saving one of its offshore drilling customers $4,000 per day in fuel costs with additional savings from the reduced cost of maintenance from burning a cleaner fuel.

Environmental

ECI dual-fuel systems substantially reduce emissions compared with unmodified counterparts, reducing NO_X emissions by 64% in locomotive applications, with further improvement in stationary power installations. Diesel particulate is also noticeably reduced. In addition, a natural gas engine requires much less maintenance and operates just as safely as a diesel or gasoline engine. It also reduces dependence on foreign-supplied fuel sources by converting operation to a domestic alternative. This product reduces NO_X emissions by over 51 tons per locomotive per year. Because of differences in duty cycles, power generator sets are estimated to provide even greater per-unit emissions savings.

Market

As of December 2000, a total of 20 systems have been sold for use in power generation, drill rig power, and locomotive applications.

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PowerRIM®

Commercial properties require high-wattage, high-quality lighting for safe visual conditions and optimum product display. Many commercial properties are excellent sites for compact fluorescent lights (CFLs); however, these settings typically use recessed downlights with incandescent and halogen lamps because standard CFLs, with their attached ballasts, cannot fit in the limited space of recessed cans. The upside-down design of the reflector cone hinders the transfer of heat generated by the lamp. For every 10 °C above the desired operating temperature, the CFL ballast life is reduced by 50%. Unfortunately, use of CFLs above 18 watts results in excessive operating temperatures, reduced light output, and destruction of the ballast. Low wattage is both ineffective and unsafe for most commercial lighting applications.

PowerRIM® is an innovative, effective adaptor to convert recessed downlights to higher-wattage CFLs. PowerRIM locates the ballast in a cool zone, providing high-quality light and eliminating early failures. The viability of the PowerRIM high-wattage CFL adaptor for recessed downlights has been demonstrated by inventor Ken Lau, of PowerLux® Corporation, with assistance from the U.S. Department of Energy Inventions and Innovation Program. The system has endured stringent performance tests by GE Lighting (40,000 cycles of 3 hours on and 20 minutes off) without deterioration of the cathodes. PowerRIM has passed UL and FCC approvals for both the commercial and residential classes of use and extends the life of the ballast while giving maximum light output, further improving the technology's economics.

The PowerRIM adaptor includes an adaptor assembly, which screws directly into the vacated incandescent socket; a CFL socket, which receives the CFL tube; the CFL tube itself; a reflector cone; and a ring-shaped glare shield baffle, which houses the ballast and is mounted at the ceiling surface. Placing the ballast in the glare shield below the lamp substantially reduces the temperature and boosts light output.

Economics

Replacing a single 100-watt incandescent fixture with a 26-watt CFL saves 600 kWh per year. PowerRIM is easily installed, eliminating the costly expense of removing existing fixtures by an electrician. CFLs last more than 10 times longer than incandescent lamps and replacement occurs much less frequently.

Environmental

Cumulative reduction in CO_2 emissions is estimated to be 820 tons through 2000.

Market

Studies have determined that over 200 million units of recessed downlights could be retrofitted with PowerRIM.

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Appendix A

REGULATIONS AND UTILITY POLICIES THAT AFFECT IMPLEMENTATION OF DISTRIBUTED ENERGY SYSTEMS

Appendix A: Regulations and Utility Policies That Affect Implementation of Distributed Energy Systems

Implementing most of the technologies in this guide should be a straight forward process of meeting commonplace technical, planning, and management requirements. However, for factory-site power systems fueled by oil, gas, biomass, or coal, regulatory hurdles combined with electric utility customer policies can raise very real obstacles. The following provides a brief overview of what a glass manufacturer is likely to encounter when assessing the potential of distributed generation. Of course, these barriers often vary regionally due to state and local utility regulations, utility customer policies, and air pollution regulations, especially those that pertain to non-attainment areas.

Utility Restructuring Issues

The U.S. electric utility industry and state and federal utility regulators have engaged in restructuring of the regulatory compact between government and utilities since the mid-1990s. Now States and regions across the country have reached various stages of opening service territories to wholesale and retail competition. One of the main concerns has been how States and utility regulatory commissions would allow their utilities to recover long-term capital investments originally made under monopolistic conditions. In the past, utilities committed large amounts of capital in exchange for authorized service territories and utility commission approved rate schedules that let them recover the investments profitably. Restructuring agreements have had to deal with these long-term capital investments, or stranded costs, which are threatened by movement towards open competition.

Along with the measures taken by the States and utility commissions to recover stranded costs, utilities have also been actively trying to retain the loads of their larger customers (i.e., industrial and commercial) in their original service territory that have indicated that they are considering on-site generation. Utilities will respond by offering a new contract for a period of several years at reduced fixed rates or by establishing discouraging requirements for administrative fees and/or services. These additional requirements can represent a potent "barrier to entry" for those interested in self-generating power. The following describes some of the barriers observed around the U.S. Only general information is provided because the requirements vary based on the utilities and utility commissions that are imposing them.

Grid Access

When an industrial plant attempts to generate on-site power to meet some or all of its electrical demand, the owner of the transmission and distribution system, typically the incumbent utility, may impose various fees on the plant. These may include:

- Exit fees;
- "Uplift" fees; and
- Back-up charges.

Utilities want to retain customer power sales as they are or find ways to offset the loss of revenue due to on-site generation. A common method is to impose exit fees. Sometimes these fees are one-time charges. More commonly a utility will choose to impose volumetric (per kW) charges for an extended period of time based on the estimated load being offset. The charges required by the utility ultimately must be approved by the utility commission.

Uplift fees are charges a utility imposes as part of its rate schedule for use of its transmission and distribution systems if excess power from the on-site generator is fed back into the grid. In some case studies, these charges have been applied even though excess power was not planned to be produced by the generator (i.e., generating capacity was less than the required load) and had no plans to sell power back to the grid.

Back-up charges are volumetric fees the utility may charge a plant based on a percentage of operating load. This percentage could be anywhere between 50% to over 100%, depending on the utility. This charge covers the potential that the utility will have to meet a significant increase in demand if the on-site prime mover is put out of service due to scheduled or unscheduled maintenance.

Interconnection

Another major implementation issue regarding on-site power systems concerns connecting to the electrical grid. Utilities have legitimate concerns about maintaining the electrical integrity of their electrical system and ensuring safety for staff that may be working on the transmission and distribution systems. Utility workers could be harmed if the grid is unexpectedly energized by an independently operated generator. Utilities want to maintain control of such potentially dangerous situations and typically want the appropriate equipment installed to avoid them.

Another interconnection issue is maintaining the stability of the utility's power grid. An independently operated generator threatens the stability of the grid if power is fed back to the grid but is not in phase, or synchronous, with grid power. The utility must have assurances that the generated power is compatible with the power the utility provides to all its customers. The Institute of Electrical and Electronic Engineers (IEEE) has been working on a national interconnection standard to guide States and utility commissions in forming and implementing a policy. Additional costs associated with on-site generation systems may originate from added interconnection equipment specified by the utility, assessment studies required to complete the project, and time delays by the utility to provide approvals throughout the process.

Regulations Related to Fossil Fuel-Fired Technologies

Regulation of air emissions produced by combusting fossil fuels can have a major impact on how industrial plants are operated. CHP technologies based on fossil fuel combustion to generate power must meet environmental standards set by the Clean Air Act (CAA). The following summarizes key items that should be considered when implementing these fossil fuel-fired technologies.

Clean Air Act

The CCA, established in 1970 and updated in 1990, sets national air quality limits, known as the National Ambient Air Quality Standards (NAAQS), that the Environmental Protection Agency (EPA) governs. State air pollution agencies are charged with establishing and enforcing local standards based on EPA limits. They have the authority to set their own local limits, which can be more stringent than the EPA limits, but not weaker; hold hearings for air permit applications; and enforce established standards with fines.

In accordance with the CAA, states submit State Implementation Plans (SIPs) that require approval by the EPA. A SIP contains a state's own air emission regulations and lays out a plan on how the state proposes to meet EPA's national limits. If a SIP is not approved, EPA would take over the management of that state's air pollution regulation activities.

EPA has defined two categories of emissions:

- Criteria Air Pollutants; and
- Hazardous Air Pollutants.

In the U.S. there are six Criteria Air Pollutants:

- ozone;
- sulfur oxides (SO_X);
- nitrous oxides (NO_X);
- carbon oxides (CO_X);
- lead; and
- particulate matter.

Acceptable levels are classified as either a Primary Standard or a Secondary Standard. A Primary Standard is established to protect health concerns and Secondary Standards are established to protect the environment and property. The Primary Standard establishes how geographic regions are to be labeled. A region will either have attained the primary standards or be placed in one of five levels of non-attainment.

The 1970 Clean Air Act has also given the EPA authority to establish an Air Toxics list that pertains to Hazardous Air Pollutants, which are chemicals released from different processes. Until the 1990 CCA amendments were adopted, there were seven chemicals listed as Air Toxics. The 1990 CCA expanded the list to 189 chemicals. Companies that release a chemical on the list have the option to voluntarily install the Maximum Available Control Technology (MACT) to avoid a prescribed method of air toxic reduction by the EPA. This regulatory area has prompted proposals to control volatile organic compound emissions by using them as an energy source for distributed generation systems.

Air Permits

Air permits are legal public documents that regulate industrial plant operations and establish federal and state reporting requirements for specified emissions. The air emission permits a company has must comply with state established standards based on EPA's National Ambient Air Quality Standards. Most operating permits require renewal in five-year intervals, but some states have different time periods. Most of these permits are regulated by the state's pollution agency, but some emission sources may require a Federally Enforceable State Operating Permit (FESOP) under the Title 5 Permit Program. These permits are issues by local authorities but are enforceable by the EPA.

New Source Review

New Source Review (NSR) refers to a regulatory process and set of rules that companies that emit air pollution trigger when they propose to construct a new energy facility or modify an existing energy plant. The pollution source owner must conduct an assessment and report it to the EPA to gain approval for its project. Although NSR technically refers to rules associated with changes to existing equipment and new installations in non-attainment areas and Prevention of Significant Deterioration (PSD) refers to rules associated to changes in attainment areas, the recent trend has been for the federal government to classify both situations as requiring a NSR assessment study.

While all regions develop their own certification criteria and process, the general practice is to require a "permit to construct" before any energy-consuming, air-polluting equipment is upgraded or installed. Once the requirements are fulfilled, a permit to operate is also required before the equipment can be used.

If proposed construction of a power plant triggers a Non-Attainment Area NSR, the owner will have to find offsets, that is, emission reductions to counterbalance an increase from the proposed construction. The offsets can be proposed within the same plant or another plant within the state, depending on applicable state regulations. Proposed offsets are not typically at a one-to-one ratio; the reduction must be a factor above the new increase. If offsets cannot be found, then the Non-Attainment NSR will require the manufacturer to design a project that implements a Lowest Achievable Emission Rate (LAER). LAER is the most effective option to bring a plant into compliance without regard to economic, energy, or environmental impacts.

If proposed construction is in an attainment area, it will trigger a compliance action based on PSD. The proposer has the opportunity to find offsets within the same plant or a plant within the state, depending on the state's regulations. If offsets cannot be found, the plant will be required to comply with Best Available Control Technology (BACT). BACT is similar to LAER, except the applicant can make an appeal to choose from a list of options ranked by effectiveness based on economic, energy, or environmental impacts.

Short-Term Outlook

Currently, over 20% of all the prime movers integrated utilities own and operate to generate electricity are over 50 years old. Old or preexisting power plant generators can escape having to comply with Clean Air Act (CAA) regulations if major changes are not incurred that trigger a New Source Review. These are called "grandfather" exemptions and they allow plants to be exempt from stricter air emission standards imposed after 1977. The CAA applies grandfathering to all plants built before 1977,

Issues that have been raised in a national debate about environmental regulations and industrial compliance may lead to new federal policies that will promote penetration and creation of incentives for distributed generation. These include "Cap and Trade" programs for NO_X and carbon, emission credits, and a Renewable Portfolio Standard (RPS) that states are enacting to require utilities to generate a small percent of their electricity using renewable energy technologies. The U.S. Department of Energy also led a review of the New Source Review regulations and in late 2002 EPA issued revisions to the policy and a proposal to clarify the definition of routine maintenance, repair and replacement (RMRR) activities.

Critics of NSR have argued that the NSR assessment requirements were onerous and prevented upgrades to old power plants and boilers that would make them more efficient and cleaner. EPA's 2002 policy changes are intended to encourage industrial and electricity-generating facilities to use best available air pollution control technologies. EPA has also sought to give plant owners more flexibility to reach and maintain compliance. The 2002 NSR revisions include several components: Plantwide Applicability Limits (PALs), a Clean Unit Provision, an Emissions Calculation Test Methodology, and Pollution Control and Prevention Projects. The final NSR rule took effect on March 3, 2003. The proposal to redefine RMRR or routine practices to allow exclusions from NSR review is not yet issued. Some States have challenged these NSR revisions and the final outcome might be adjusted in the future. Presently, it should be easier for a manufacturer to permit a distributed generation facility.

Clean High-Efficiency Technology Standard (CHET)

The Federal government is exploring a new type of standard called a CHET that would apply to small-scale CHP systems. Energy efficiency and emission performance standards would be met by the manufacturer of the CHP system as a packaged unit, not by the user/owner; this allows manufacturers to install these pre-approved systems on a turn-key basis without additional permitting. (Federal Strategies to Increase the Implementation of Combined Heat and Power Technologies in the United States)

Output-Based Standards

Emissions from fuel burning equipment are limited based on how much fuel it burns. The accounting system used to calculate the limit does not take into account operating efficiency; therefore, it does not reward measures to increase efficiency.

"Output standards" based on the fuel input per output (e.g., cubic feet of gas per kWh) are being explored to replace the current fuel input accounting system to take into account increases in efficiency. This change would be favorable to CHP systems utilizing waste heat (wasted energy in systems solely generating electricity), which would increase the "output" ratio given the same level of fuel input.

Air Quality Standards for Ground Level Pollutants

Particulate emissions, especially those from the combustion of Diesel fuel, are becoming a more prominent environmental issue. Another concern from these emissions is production of ground level ozone, a contributor to regional haze. Both impact health. A new program is being developed to control ground level ozone and reduce particulate and sulfur emissions from diesel internal combustion engines.

In summary, manufacturers should not be discouraged by the utility policy and emission regulations requirements they may face when it comes to implementing distributed energy resource projects. The Department of Energy is aggressively promoting more distributed energy generation to make the economy more efficient and reduce overall emission of pollutants. It should be evident too, that incorporating renewable energy technologies that emit no pollutants when they generate electricity or thermal energy will ease regulatory burdens on manufacturers and can create valuable offsets for expansion of fossil-energy consumption.

Appendix B

ECONOMIC INCENTIVES AND LIFE-CYCLE COSTS

Appendix B: Economic Incentives and Life-cycle Costs

Every company operates under its own unique culture and standards that set strategic priorities with regard to production rates, production quality, acquisition of goods and services, growth, and customer service. Capital is allocated on the basis of these company values and cost effectiveness guidelines that contribute to company profitability. Adopting increased energy efficiency and lower environmental emissions as strategic goals will contribute to a company's "bottom-line" success. More than a few firms have found that energy efficiency combined with environmental stewardship has actually cut production costs and improved business.

It is fairly common that many industrial companies calculate simple payback for energy efficiency options and if a project does not pencil in a return of the capital allocated to it in less than 12 to 18 months, it is not likely to be implemented. Appendix B presents information about financial incentives for energy projects that are available from the federal and state governments and utilities. Adding the value of these incentives to simple payback calculations can help projects cross a company's approval hurdle. Appendix B also presents the elements for using life-cycle cost analysis to support strategies predicated on improving energy efficiency and reducing emissions.

Types of Financial Incentives

Investment Tax Incentives

Corporations can receive credits or deductions ranging from 10% to 50% against the cost of renewable energy equipment or installation. In some cases, the incentive decreases over time. Some states allow the tax credit only if a corporation has invested a certain dollar amount into a given renewable energy project. In most cases, there is no maximum limit imposed on the amount of the deductible item or credit.

Sales Tax Incentives

Renewable energy equipment purchases may be exempt from a state sales tax.

Property Tax Incentives

Property tax incentives typically follow one of three basic structures: exemptions, exclusions, and credits. The majority of the property tax provisions for renewable energy follow a simple model that exempts the added value of the renewable device from being included in the valuation of the property for taxation purposes. That is, if a renewable energy heating system costs $1,500 to install versus $1,000 for a conventional heating system, then the renewable energy system is assessed at $1,000.

Property taxes are collected locally, so some states allow local authorities the option of providing a property tax incentive for renewable energy devices. Six states have such provisions: New Hampshire, Iowa, Connecticut, Maryland, Vermont, and Virginia.

Rebate Programs

Rebate programs are offered at the state, local, and utility levels to promote installation of renewable energy equipment. The majority of the programs are available from state agencies and municipally-owned utilities and support solar water heating and/or photovoltaic systems. Residential and commercial businesses are usually eligible; however, some programs are available to industry, institutions, and government agencies as well. Rebates typically range from $150 to $4,000. In some cases, rebate programs are combined with low- or no-interest loans.

To pay for energy efficiency, a number of states that have deregulated their utilities have established funds with monies from the rate payers—most often called "public benefit charges." These funds can be administered by the utility or by a state agency.

As an example, Pacific Gas & Electric Company in California offered business rebates for HVAC equipment, lighting technologies, LED fixtures, and motors. Investments in gas use efficiency were also eligible for a one-time payment based on the amount of gas conserved in the first year. In Wisconsin, a portion of public benefit charge funds was directed to the Energy Center of Wisconsin ($2 million in FY2003) to encourage industrial energy efficiency. The Energy Center facilitates and funds public-private partnerships to develop and demonstrate new technology. It also supports evaluations of new process technologies in production environments and pays for services and feasibility studies, demonstration trials, data collection, testing services, and analysis of results for industrial energy efficiency projects. These are but two examples of programs that exist.

Grant Programs

Most state grant programs offer support for a broad range of renewable energy technologies, while some states focus on promoting one particular type of renewable energy, such as wind technology or alternative fuels.

Grants are available primarily to the commercial, industrial, utility, education, and government sectors. Some grant programs focus on research and development, while others are designed to help a project achieve commercialization. Programs vary in the amount offered–from $500 to $1,000,000–with some states not setting a limit.

Loan Programs

Utilities commonly offer low-interest or no-interest loans for energy efficiency as part of their demand-side management programs. State governments also offer financing to assist in the purchase of renewable energy equipment. A broad range of renewable energy technologies are eligible. In many states, loans are available to residential, commercial, industrial, transportation, public, and nonprofit sectors. Repayment schedules vary; while most are determined on an individual project basis, some offer a 7- to 10-year loan term.

Industrial Recruitment Incentives

This category focuses on special efforts and programs designed to attract renewable energy equipment manufacturers to locate within a city or state. Renewable energy industrial recruitment usually consists of financial incentives such as tax credits, grants, or a commitment to purchase a specific amount of the product for use by a government agency.

The recruitment incentives are designed to attract industries that will benefit the environment and create jobs. In most cases, the financial incentives are temporary measures that will help support the industries in their early years. They can include a sunset provision to encourage the industries to become self-sufficient in a desired period of time.

Leasing/Lease Purchase Programs
Utility leasing programs target remote power customers for which line extension would be very costly. The customers can lease the technology (e.g., photovoltaics) from the utility, and in some cases, the customer can opt to purchase the system after a specified number of years.

Direct Equipment Sales
A few utilities sell renewable energy equipment to their customers as part of a buy-down, low-income assistance, lease, or remote power program.

Production Incentives
Production incentives provide credits or payments based on actual energy output (e.g., cents per kilowatt-hour or gallon of ethanol). These programs offer an advantage over incentives based on investment in that production payments and credits place a premium on project output and hence quality–not just rated capacity, which may or may not be fully utilized once installed.

A handful of states offer these incentives for several types of renewable energy - micro hydro, solar, wind, and biofuels. The Federal Renewable Energy Production Incentive (REPI) provides financial incentive payments for electricity produced and sold by new qualifying renewable energy generation facilities.

Summary of Federal Renewable Energy Tax Incentives for Business

Solar Business Energy Tax Credit

Incentive Type:	Corporate Tax Credit
Eligible Technologies:	Solar Water Heat, Active Solar Space Heat, Solar Thermal Electric, Solar Thermal Process Heat, Photovoltaics, Geothermal Electric
Applicable Sectors:	Commercial, Industrial
Amount:	10%
Max. Limit:	$25,000 per year, plus 25% of the total tax remaining after the credit is taken
Terms:	Credit may be carried back to the 3 preceding years and then carried forward for 15 years
Expiration Date:	None
Website:	http://www.mdv-seia.org/federal_incentives.htm
Authority 1:	U.S. Code Citation: 26 USC 48

Summary:
The federal business energy tax credit is a 10% tax credit available to commercial businesses that invest in or purchase energy property in the United States. Energy property is defined as either solar or geothermal energy. Solar energy property includes equipment that uses solar energy to generate electricity, heat or cool (or provide hot water for use in) a structure, or

provide solar process heat. Geothermal energy property includes equipment used to produce, distribute, or use energy derived from a geothermal deposit. For electricity produced by geothermal power, equipment qualifies only up to, but not including, the electrical transmission stage.

The energy property must be operational in the year in which the credit is first taken. The property must also be constructed by the taxpayer and used by the taxpayer. Energy property does not include public utility property, passive solar systems, pool heating, or equipment used to generate steam for industrial or commercial processes.

There are cases when the full 10% credit cannot be taken. If the solar energy property is financed in whole or in part by subsidized energy financing or by tax-exempt private activity bonds, the credit may taken only on the portion of the investment or purchase that is not subsidized. For example, if for a $100,000 investment (otherwise known as the cost or basis) $20,000 is allocable to subsidized financing or tax-exempt private activity bonds, the credit would amount to 10% of $80,000. In addition, the cost or basis of property for investment credit purposes may be limited if money is borrowed against the property and the borrower is protected against loss, or if the borrower borrowed money from a person who is related, or who has other than a creditor interest in the business activity. In these cases, the cost or basis must be reduced by the amount of this "nonqualified non-recourse financing" as of the close of the tax year in which it is placed in service.

The tax credit is limited to $25,000 per year, plus 25% of the total tax remaining after the credit is taken. The remaining credit balance may be carried back to the 3 preceding years and then carried forward for 15 years.

The Energy Policy Act of 1992 ensures that this tax credit has no expiration date. Form 3468 is used to claim the investment credit. The IRS general website listed below provides a "Forms and Publications Finder."

Contact:
Information Specialist
IRS Internal Revenue Service
1111 Constitution Avenue, NW
Washington, District of Columbia 20224
Tel: (800) 829-1040
Website: http://www.irs.gov

Federal Solar, Wind, and Geothermal Modified Accelerated Cost Recovery System (MACRS)

Incentive Type:	Corporate Depreciation
Eligible Technologies:	Solar Water Heat, Active Solar Space Heat, Solar Thermal Electric, Solar Thermal Process Heat, Photovoltaics, Wind, Geothermal Electric
Applicable Sectors:	Commercial, Industrial
Amount:	Varies
Terms:	5 years
Effective Date:	1986
Website:	http://www.eren.doe.gov/consumerinfo/refbriefs/la7.html
Authority 1:	U.S. Code Citation: 26 USC 168

Summary:

Under the Modified Accelerated Cost Recovery System (MACRS), businesses can recover investments in solar, wind, and geothermal property through depreciation deductions. The MACRS establishes a set of class lives for various types of property, ranging from 3 to 50 years, over which the property may be depreciated. For solar, wind, and geothermal property placed in service after 1986, the current MACRS property class is 5 years.

In addition to the MACRS depreciation, the Job Creation and Worker Assistance Act of 2002 allows businesses to take an additional 30% depreciation on solar, wind, and geothermal property in the first year. The 30% depreciation only applies to property purchased after September 10, 2001, and before September 11, 2004, which is placed in service before January 1, 2005.

For more information on and to claim MACRS see IRS Publication 946, IRS Form 4562: Depreciation and Amortization and Instructions for Form 4562, and Internal Revenue Code Sec. 168(e)(3)(B)(vi). The IRS general website listed below provides a "Forms and Publications Finder."

Contact:
Information Specialist - IRS Internal Revenue Service 1111 Constitution Avenue, NW, Washington, District of Columbia, 20224
Tel: (800) 829-1040
Website: http://www.irs.gov

5-year MACRS Depreciation Schedule

Method: 200% declining balance switching to straight line
Convention: Half-year

Year Depreciation Schedule Amount

1.	20.00%	MACRS—18% of basis + 30% of remaining basis = 39% in year one.
2.	32.00%	
3.	19.20%	
4.	11.52%	
5.	11.52%	
6.	5.76%	

Net Metering

Across the United States, 34 states have put in place provisions that allow owners of solar energy systems that are "grid tied" to "trade" electricity back and forth with their serving utility at a single price. This is called "net metering." These laws or utility commission rules were put into place to help make solar-electric technologies more competitive. Net metering responded primarily to homeowner concerns related to the Public Utilities Regulatory Policy Act of 1978 (PURPA) that required utilities to purchase energy from small power producers who have systems under 100 kilowatts in capacity. The utility pays an avoided cost amount that the public service or state corporate commission approves, but these avoided costs were very low, less than 2 cents per kilowatt-hour, so that a homeowner would only receive 2 cents a kilowatt-hour for electricity sent to the utility, but would be paying anywhere from 5 to 17 cents a kilowatt-hour for electricity bought from the utility. Under these conditions, little incentive existed for the homeowner to put in a larger PV system that would give the utility new, practically free, generation capacity that is most available on hot, sunny days. Net metering benefits a utility as well as a homeowner, and many states have extended net metering to apply to businesses.

In summary, net metering:

- Rewards consumers for early adoption of renewable energy technologies by reducing their utility bills and increasing the value of their solar energy systems;
- Rewards utilities and ratepayers with system benefits and cost savings that exceed revenue loss;
- Enhances public appreciation for utilities for adopting environmentally responsible programs and increase business for companies that manufacture and install solar energy equipment;
- Improves utility marketing prospects if they decide to enter the customer-sited PV or other solar technology markets themselves; and
- Diversifies energy supply, reduces pollution, and may avoid imported fuel costs for certain states.

In time, one can expect utilities to invest in micro-generation plants spread throughout their service territories to cut energy demand where substations and power plants are struggling to meet the loads. Until utilities are convinced that investment in distributed, small power generation really is a profitable approach for them, net metering has begun establishing the value of this approach especially with utility deregulation.

For large manufacturing facilities, the retail pricing of excess electricity under a net metering rule is not likely to have much meaning because the solar energy system will never generate more electricity than the corporation requires. However, the net metering provisions will make it easier for manufacturers to install solar and other renewable energy systems that are grid tied. Net metering could figure in situations where a plant has separate utility meters for particular loads and if the load were small enough and an 80-kW system qualified for net metering, the corporation could benefit from the excess energy sold at retail to the utility, as well as from peak load shaving.

The tables below provide information on the net metering rules and regulations that 34 states have enacted. In some of these states, net metering is restricted to residential customers. In others, the provisions cover wind energy and biomass energy, as well as solar energy systems.

Summary of State Net Metering Programs

This table was last updated on 6/3/2003

State	Allowable Technologies	Allowable Customers	Statewide Capacity Limit	Treatment of Excess Generation (NEG)	Implementation Authority	Enacted	Utilities Covered	Citation/Reference
Arizona	Renewables and cogeneration <= 100 kW	All customer classes	None	NEG purchased at avoided cost	Arizona Corporation Commission	1981	All IOUs and RECs	PUC Order Decision 52345, Docket 81-045
Arkansas	Renewables, fuel cells, and microturbines <= 25 kW residential <= 100 kW commercial	All customer classes	None	Monthly NEG granted to utilities	Legislature	2001	All utilities	HB 2325, effective 11/01; PSC Order No. 3 July 3, 2002
California	Solar and wind <= 1,000 kW	All customer classes	0.5% of utility's peak demand	Annual NEG granted to utilities	Legislature	2002; 2001; 1995	All utilities	Public Utilities Codes Sec. 2827 (amended 09/02; 04/01; effective 09/98)
Colorado	Wind and PV 3 kW, 10 kW	Varies	NA	Varies	Utility tariffs	1997	Four Colorado utilities	PSCO Advice Letter 1265; PUC Decision C96-901 [1]
Connecticut	Renewables and fuel cells <=100 kW	Residential	None	Not specified	Legislature	1990, updated 1998	All IOUs, No REC in state	CGS 16-243H; Public Act 98-28
Delaware	Renewables <= 25 kW	All customer classes	None	Not specified	Legislature	1999	All utilities	Senate Amendment No. 1 to HB 10
Georgia	Solar, wind, fuel cells <= 10kW residential <= 100 kW commerical	Residential and commercial	0.2% of annual peak demand	Monthly NEG or total generation purchased at avoided cost or higher rate if green priced	Legislature	2001	All utilities	SB93
Hawaii	Solar, wind, biomass, hydro <= 10kW	Residential and small commercial	0.5% of annual peak demand	Monthly NEG granted to utilities	Legislature	2001	All utilities	HB 173

Summary of State Net Metering Programs

This table was last updated on 6/3/2003

State	Allowable Technologies	Allowable Customers	Statewide Capacity Limit	Treatment of Excess Generation (NEG)	Implementation Authority	Enacted	Utilities Covered	Citation/Reference
Idaho	All technologies <= 100 kW	Residential and small commercial (Idaho Power only)	None	Monthly NEG purchased at avoided cost	Public Utility Commission	1980	IOUs only, RECs are not rate-regulated	Idaho PUC Order #16025 and #26750 (1997) Tariff sheets 86-1 thru 86-7
Illinois	Solar and wind <= 40 kW	All customer classes; ComEd only	0.1% of annual peak demand	NEG purchased at avoided cost	ComEd tariff	2000	Commonwealth Edison	Special billing experiment [1]
Indiana	Renewables and cogeneration <= 1,000 kWh/month	All customer classes	None	Monthly NEG granted to utilities	Public Utility Commission	1985	IOUs only, RECs are not rate-regulated	Code 4-4.1-7
Iowa	Renewable and cogeneration (No limit per system)	All customer classes	105 MW	Monthly NEG purchased at avoided cost	Iowa Utility Board	1993	IOUs only, RECs are not rate-regulated [2]	Iowa Administrative Code [199] Chapter 15.11(5)
Maine	Renewables and fuel cells <= 100 kW	All customer classes	None	Annual NEG granted to utilities	Public Utility Commission	1998	All utilities	Order #98-621 RC of ME Chapter 36
Maryland	Solar only <= 80 kW	Residential and schools only	0.2% of 1998 peak	Monthly NEG granted to utilities	Legislature	1997	All utilities	Article 78, Section 54M
Massachusetts	Qualifying facilities <= 60 kW	All customer classes	None	Monthly NEG purchased at avoided cost	Legislature	1997	All utilities	Mass. Gen. L. ch. 164, 1G(g); Dept. of Tel. and Energy 97-111
Minnesota	Qualifying facilities <= 40 kW	All customer classes	None	NEG purchased at utility average retail energy rate	Legislature	1983	All utilities	Minn. Stat. 216B.164

Summary of State Net Metering Programs

This table was last updated on 6/3/2003

State	Allowable Technologies	Allowable Customers	Statewide Capacity Limit	Treatment of Excess Generation (NEG)	Implementation Authority	Enacted	Utilities Covered	Citation/Reference
Montana	Solar, wind, and hydro <= 50 kW	All customer classes	None	Annual NEG granted to utilities at the end of each calendar yr.	Legislature	1999	IOUs only	SB 409
Nevada	Solar and wind <= 10 kW	All customer classes	None	Monthly or annual NEG granted to utilities	Legislature	2001; 1997	All utilities	Nevada Revised Statute Ch. 704; amended AB661 (2001)
New Hampshire	Solar, wind, and hydro <= 25 kW	All customer classes	0.05% of utility's annual peak	NEG credited to next month	Legislature	1998	All utilities	RSA 362-A:2 (HB 485)
New Jersey	PV and wind <= 100 kW	Residential and small commercial	0.1% of peak or $2M annual financial impact	Annualized NEG purchased or avoided cost	Legislature	1999	All utilities	AB 16. Electric Discount and Energy Competition Act
New Mexico	Renewables and cogeneration <= 10 kW	All customer classes	None	NEG credited to next month, or monthly NEG purchased at avoided cost (utility choice)	Public Utility Commission	1999	All utilities	NMPUC Rule 571, 17 NMAC 10.571
New York	Solar only residential <= 10 kW; Farm biogas systems < 400 kW	Residential; farm systems	0.1% of 1996 peak demand	Annualized NEG purchased at avoided cost	Legislature	2002; 1997	All utilities	Laws of New York, 1997, Chapter 399; amended SB 6592 (2002)
North Dakota	Renewables and cogeneration <= 100 kW	All customer classes	None	Monthly NEG purchased at avoided cost	Public Utility Commission	1991	IOUs only, RECs are not rate-regulate-d	North Dakota Admin. Code 69-09-07-09

Summary of State Net Metering Programs

This table was last updated on 6/3/2003

State	Allowable Technologies	Allowable Customers	Statewide Capacity Limit	Treatment of Excess Generation (NEG)	Implementation Authority	Enacted	Utilities Covered	Citation/Reference
Ohio	Renewables, micro-turbines, and fuel cells (no limit per system)	All customer classes	1.0% of aggregate customer demand	NEG credited to next month	Legislature	1999	All utilities	S.B. 3 (effective 01/01/01)
Oklahoma	Renewables and cogeneration <= 100 kW and <= 25,000 kWh/year	All customer classes	None	Monthly NEG granted to utility	Oklahoma Corporation Commission	1988	All utilities	OCC Order 326195
Oregon	Solar, wind, fuel cells, and hydro <= 25 kW	All customer classes	0.5% of peak demand	Annual NEG granted to low-income programs credited to customer, or other use determined by Commission	Legislature	1999	All utilities	H.B. 3219 (effective 09/01/99)
Pennsylvania	Renewables and fuel cells <= 10 kW	Residential	None	Monthly NEG granted to utility	Legislature	1998	All utilities	52 PA Code 57.34
Rhode Island	Renewables and fuel cells <= 25 kW	All customer classes	1 MW for Narragansett Electric Co.	Annual NEG granted to utilities	Public Utility Commission	1998	Narragansett Electric Comapny	PUC Order Docket No. 2710
Texas	Renewables only <= 50 kW	All customer classes	None	Monthly NEG purchased at avoided cost	Public Utility Commission	1986	All IOUs and RECs	PUC of Texas, Substantive Rules, 23.66(f)(4)
Vermont	PV, wind, fuel cells <=15 kW Farm biogas <=150 kW	Residential, commercial, and agricultural	1.0% of 1996 peak	Annual NEG granted to utilities	Legislature	1998	All utilities	Sec. 2. 30 V.S.A. 219a; amended Senate Bill 138, 2002

Summary of State Net Metering Programs

This table was last updated on 6/3/2003

State	Allowable Technologies	Allowable Customers	Statewide Capacity Limit	Treatment of Excess Generation (NEG)	Implementation Authority	Enacted	Utilities Covered	Citation/Reference
Virginia	Solar, wind, and hydro Residential <= 10 kW Non-residential <= 25 kW	All customer classes	0.1% of peak of previous year	Annual NEG granted to utilities (power purchase agreement is allowed)	Legislature	1999	All utilities	Virginia Assembly S1269 Approved by both Assembly and Senate 03/15/99
Washington	Solar, wind, fuel cells, and hydro <= 25 kW	All customer classes	0.1% of 1996 peak demand	Annual NEG granted to utility	Legislature	1998	All utilities	Title 80 RCW House Bill B2773
Wisconsin	All technologies <= 20 kW	All retail customers	None	Monthly NEG purchased at retail rate for renewables, avoided cost for non-renewables	Public Service Commission	1993	IOUs only, RECs are not rate-regulated	PSCW Order 6690-UR-107
Wyoming	Solar, wind, and hydro <= 25 kW	All customer classes	None	Annual NEG purchased at avoided cost	Legislature	2001	All IOUs and RECs	HB 195, Feb. 2001

Notes: IOU: Investor-owned Utility
G and T: Generation and Transmission Cooperative
REC: Rural Electric Cooperative

[1] For information, see the Database of State Incentives for Renewable Energy (http://www.dcs.ncsu.edu/solar/dsire/dsire.cfm).
[2] Except for the Linn County Electric Cooperative, which is rate-regulated by Iowa PUC

The original format for this table is taken from: Thomas J. Starrs (September 1996). *Net Metering: New Opportunities for Home Power.* Renewable Energy Policy Project, Issue Brief No. 2, College Park, MD: University of Maryland.

Summary of Incentives by State

The pages in the following section summarize (in columns and then matricies) various financial incentives by state. Following the three tables are expanded profiles for four states with large glass industries. More specifics on the programs in other states that are summarized in the tables are available at www.dsireusa.org.

The following information was extracted from the Database of State Incentives for Renewable Energy (DSIRE)—a comprehensive source of information on state, local, utility, and selected federal incentives that promote renewable energy.

Alabama:

Grants:	State (1)
Loans:	Utility (1)

Alaska:

Sales Tax:	State (1)
Loans:	State (1)

Arizona:

Sales Tax:	State (1)
Rebates:	Utility (2)
Equipment Sales:	Utility (2)

Arkansas:

Corporate Tax:	State (1)
Industry Recruitment:	State (1)

California:

Corporate Tax:	State (1)
Property Tax:	State (1)
Rebates:	State (3)
	Utility (8)
Grants:	State (3)
Loans:	State (2)
	Utility (2)
Industry Recruitment:	State (1)
Leasing Programs:	Utility (2)
Equipment Sales:	Utility (1)

Colorado:

Corporate Tax:	State (1)
Rebates:	Local (1)
Production Incentives:	Local (2)

Connecticut:

Corporate Tax:	State (2)
Sales Tax:	State (1)
Property Tax:	State (1)
Loans:	State (1)

Delaware:

Rebates:	State (1)

District of Columbia:

[None]

Florida:

Sales Tax:	State (1)
Rebates:	Utility (2)
Grants:	Utility (1)

Georgia:

Corporate Tax:	State (1)

Hawaii:

Corporate Tax:	State (3)
Sales Tax:	State (1)
Rebates:	State (1)
	Utility (3)
Loans:	Local (2)
Industry Recruitment:	State (1)

Idaho:

Loans:	State (1)

Illinois:

Property Tax:	State (1)
Rebates:	State (1)
Grants:	State (2)

Indiana:

Property Tax:	State (1)
Grants:	State (5)

Iowa:

Corporate Tax:	State (1)
Sales Tax:	State (2)
Property Tax:	State (3)
Grants:	State (1)
Loans:	State (3)

Kansas:

Corporate Tax:	State (1)
Property Tax:	State (1)
Grants:	State (1)

Kentucky:

[None]

Louisiana:

[None]

Maine:

[None]

Maryland:

Corporate Tax:	State (2)
Sales Tax:	State (2)
Property Tax:	State (1)
Rebates:	State (1)
Loans:	State (2)

Massachusetts:

Corporate Tax:	State (3)
Sales Tax:	State (1)
Property Tax:	State (1)
Rebates:	State (1)
Grants:	State (2)

Michigan:

Grants:	State (1)

Minnesota:

Sales Tax:	State (2)
Property Tax:	State (1)
Rebates:	State (1)
Loans:	State (2)
Production Incentives:	State (2)

Mississippi:

Loans:	State (1)

Missouri:

Corporate Tax:	State (1)
Loans:	State (1)

Montana:

Corporate Tax:	State (1)
Property Tax:	State (1)
Grants:	State (1)
Loans:	State (1)
Industry Recruitment:	State (1)
Equipment Sales:	Utility (1)

Nebraska:

Loans:	State (1)
Production Incentives:	State (1)

Nevada:

Sales Tax:	State (1)
Property Tax:	State (2)
Rebates:	Utility (2)

New Hampshire:

Property Tax:	State (1)

New Jersey:

Sales Tax:	State (1)
Rebates:	State (1)

New Mexico:

Corporate Tax:	State (1)

New York:

Corporate Tax:	State (1)
Property Tax:	State (1)
Rebates:	State (2)
	Utility (1)
Grants:	State (1)
Loans:	State (1)

North Carolina:

Corporate Tax:	State (1)
Property Tax:	State (1)
Loans:	State (1)
Industry Recruitment:	State (1)

North Dakota:

Corporate Tax:	State (1)
Sales Tax:	State (1)
Property Tax:	State (2)

Ohio:

Corporate Tax:	State (2)
Sales Tax:	State (1)
Property Tax:	State (1)
Loans:	State (1)

Oklahoma:

Corporate Tax:	State (1)
Industry Recruitment:	State (1)

Oregon:

Corporate Tax:	State (1)
Property Tax:	State (1)
Rebates:	Utility (4)
Loans:	State (1)
	Utility (3)
Production Incentives:	State (1)

Pennsylvania:

Rebates:	Local (1)
Grants:	State (1)
	Local (3)
Loans:	Local (3)
Production Incentives:	Utility (1)

Rhode Island:

Sales Tax:	State (1)
Property Tax:	State (1)
Rebates:	State (2)
Grants:	State (1)

South Carolina:

Rebates:	Utility (1)

South Dakota:

Property Tax:	State (1)

Tennessee:

Loans:	State (1)

Texas:

Corporate Tax:	State (1)
Property Tax:	State (1)
Rebates:	Utility (1)
Industry Recruitment:	State (1)
Leasing Programs:	Utility (1)

Utah:

Corporate Tax:	State (1)

Vermont:

Sales Tax:	State (1)
Property Tax:	State (1)

Virginia:

Property Tax:	State (1)
Loans:	State (1)
Industry Recruitment:	State (1)

Washington:

Sales Tax:	State (1)
Rebates:	State (1)
	Utility (1)
Loans:	Utility (1)
	Local (1)
Industry Recruitment:	State (1)
Production Incentives:	Utility (1)
	Local (1)

West Virginia:

Corporate Tax:	State (1)
Property Tax:	State (1)

Wisconsin:

Property Tax:	State (1)
Rebates:	State (1)
	Utility (1)
Grants:	State (1)
Loans:	State (1)

Wyoming:

Leasing Programs:	Utility (1)
Equipment Sales:	Utility (1)

Matrix of State and Selected Federal Financial Incentives										
S=State; **L**=Local; **U**=Utility/Energy Service Co.						Source: www.dsireusa.org; 11/01/02				
State	Corporate Tax	Sales Tax	Property Tax	Rebates	Grants	Loans	Industry Recruit.	Leasing Programs	Equip. Sales	Production Incentives
Fed.	6					2				1
AL					1-S	1-U				
AK		1-S				1-S				
AZ		1-S		2-U					2-U	
AR	1-S						1-S			
CA	1-S		1-S	3-S, 8-U	3-S	2-S, 2-U	1-S	2-U	1-U	
CO	1-S			1-L						2-L
CT	2-S	1-S	1-S			1-S				
DE				1-S						
DC										
FL		1-S		2-U	1-U					
GA	1-S									
HI	3-S	1-S		1-S, 3-U		2-L	1-S			
ID						1-S				
IL			1-S	1-S	2-S					
IN			1-S		5-S					
IA	1-S	2-S	3-S		1-S	3-S				
KA	1-S		1-S		1-S					

Matrix of State and Selected Federal Financial Incentives										
S=State; **L**=Local; **U**=Utility/Energy Service Co.						Source: www.dsireusa.org; 11/01/02				
State	Corporate Tax	Sales Tax	Property Tax	Rebates	Grants	Loans	Industry Recruit.	Leasing Programs	Equip. Sales	Production Incentives
KY										
LA										
ME										
MD	2-S	2-S	1-S	1-S		2-S				
MA	3-S	1-S	1-S	1-S	2-S					
MI					1-S					
MN		2-S	1-S	1-S		2-S				2-S
MS						1-S				
MO	1-S					1-S				
MT	1-S		1-S		1-S	1-S	1-S		1-U	
NE						1-S				1-S
NV		1-S	2-S	2-U						
NH			1-S							
NJ		1-S		1-S						
NM	1-S									
NY	1-S		1-S	2-S, 1-U	1-S	1-S				
NC	1-S		1-S			1-S	1-S			
ND	1-S	1-S	2-S							
OH	2-S	1-S	1-S			1-S				

Matrix of State and Selected Federal Financial Incentives										
S=State; **L**=Local; **U**=Utility/Energy Service Co.						Source: www.dsireusa.org; 11/01/02				
State	Corporate Tax	Sales Tax	Property Tax	Rebates	Grants	Loans	Industry Recruit.	Leasing Programs	Equip. Sales	Production Incentives
OK	1-S						1-S			
OR	1-S		1-S	4-U		1-S, 3-U				1-S
PA				1-L	1-S, 3-L	3-L				1-U
RI		1-S	1-S	2-S	1-S					
SC				1-U						
SD			1-S							
TN						1-S				
TX	1-S		1-S	1-U			1-S	1-U		
UT	1-S									
VT		1-S	1-S							
VA			1-S			1-S	1-S			
WA		1-S		1-S, 1-U		1-U, 1-L	1-S			1-U, 1-L
WV	1-S		1-S							
WI			1-S	1-S, 1-U	1-S	1-S				
WY								1-U	1-U	
Totals	29	19	28	44	25	36	9	4	5	9

Pennsylvania

Net Metering: Yes

Local Rebate Program

Sustainable Development Fund Solar PV Grant Program (PECO Territory)

Last DSIRE Review:	03/14/20033
Incentive Type:	Local Rebate Program3
Eligible Technologies:	Photovoltaics3
Applicable Sectors:	Commercial, Industrial, Residential, PECO Service Territory3
Rebate:	$4/watt up to $20,000; then $1/kWh produced in first year of3 production up to $5,000
Max. Limit:	$25,000 or 80% of the total installed cost of the PV system
Terms:	1kW to 5kW systems are eligible 17 Solar PV Systems have been installed or are pending installation to date with a total capacity of 54.47 kW
Date Enacted:	10/01
Effective Date:	12/5/01
Website:	http://www.trfund.com/sdf/solarpv/index.html

Summary:

The Sustainable Development Fund offers grants for PV systems that are purchased by3 PECO Energy distribution company customers. Systems between 1 kW and 5 kW are3 eligible; preference will be given to systems that will be interconnected to the electric grid.3 Each system must meet the program's hardware and installation standards and be installed3 by participating contractors. All systems must be inspected and certified by the program3 administrator to ensure they comply with program requirements. In addition, the system3 owner must agree to allow the system to be used for research purposes and promotion of3 the program.3

The program was launched in December 2001 and attracted five participants in its first 93 months. The PV grant is paid in several installments based in part on system performance.3 This includes the following 3-prong subsidy:3

Buy-down Incentive* => PV System Owner via the Participating Contractor3
$4/watt (Rated PV Capacity @ STC) up to $20,000 [through 2003, then $3/watt up to3 $15,000]3

Performance Incentive => PV System Owner3
$1/kWh of Gross Solar Production in the first year up to $5,0003

Performance Incentive => Participating Contractor3
$0.10/kWh of Gross Solar Production in the first year up to $2503

The first payment of $4/watt up to $20,000 will be made upon inspection and approval of the installed system. This payment is made to the installer of the PV system. All partici4 pating contractors have agreed to credit the system buyers with this payment.

The second payment is made at the first anniversary of the system and is equal to $1 per kilowatt-hour that the system has produced during the first 12 months of operation, up to a maximum payment of $5,000. At the same time, a payment will be made to the system installer equal to $0.10 per kWh generated by the system during these 12 months of operation, up to a maximum payment of $250 per system. The two later payments will give both the owner and the installer a significant incentive to monitor system perfor4 mance and to make certain that the system is performing well.

To date, 17 Solar PV Systems have been installed or are pending installation with a total capacity of 54.47 kW.

Local Grant Programs

Metropolitan Edison Company SEF (FirstEnergy Territory)

Last DSIRE Review:	03/06/20033
Incentive Type:	Local Grant Program3
Eligible Technologies:	Passive Solar Space Heat, Solar Water Heat, Active Solar Space Heat,3 Solar Thermal Electric, Solar Thermal Process Heat, Photovoltaics, Landfill Gas, Wind, Biomass, Hydro, Fuel Cells, Waste, Cogenera4 tion, Solar
Applicable Sectors:	Commercial, Industrial, Residential, Nonprofit, Schools, Metropoli4 tan Edison Territory of FirstEnergy
Amount:	Varies according to project
Max. Limit:	$1,000,000
Terms:	Varies according to project
Date Enacted:	2000
Effective Date:	2000

Summary:

FirstEnergy (formerly GPU) established the Metropolitan Edison Company Sustainable Energy Fund (SEF) and the Penelec Sustainable Energy Fund in 2000.

The Metropolitan Edison Company SEF was created with an initial contribution of $5,700,000 and is administered by the Berks County Community Foundation.

The purpose of the fund is to promote:

- The development and use of renewable energy and clean energy technologies;3
- Energy conservation and efficiency;3
- Sustainable energy businesses; and3
- Projects that improve the environment in the companies' service territories, as3 defined by their relationship to the companies' transmission and distribution facilities.

The majority of funding available from the Meropolitan Edison Company SEF will be in the form of investments made in businesses that are pursuing one or more of the fund's purposes.

SEF of Central Eastern Pennsylvania Grant Program (PP&L Territory)

Last DSIRE Review:	03/06/20033
Incentive Type:	Local Grant Program3
Eligible Technologies:	Solar Water Heat, Active Solar Space Heat, Photovoltaics, Landfill3 Gas, Wind, Biomass, Hydro, Fuel Cells, Solar
Applicable Sectors:	Commercial, Industrial, Nonprofit, Schools, Local Government, Utilities, State Government, PP&L Service Territory
Amount:	Generally $10,000 - $25,000
Max. Limit:	$25,000
Effective Date:	2000
Website:	http://www.sustainableenergyfund.org

Summary:

The Sustainable Energy Fund (SEF) of Central Eastern Pennsylvania disburses a limited number of grants and loans to organizations seeking funding for projects consistent with the Fund's mission. SEF's mission is "to promote, research, and invest in clean and renewable energy technologies, energy conservation, energy efficiency, and sustainable energy enterprises that provide opportunities and benefits for PP&L ratepayers." Currently, 60% of the funds are disbursed towards loans, 7% towards educational grants, and 33% towards royalty and equity financing.

The SEF was founded in November 1999 as a result of the Pennsylvania Public Utility Commission (PUC) electric utility restructuring proceedings. The SEF was a key compo4 nent of the joint settlement with PP&L, Inc., (now PP&L Electric Utilities Corporation) and the PUC. The initial SEF funding of approximately $20.5 million will be generated over 6 years through a rate surcharge on PPL ratepayers. See DSIRE's summary of Pennsylvania's Public Benefits Funds.

Sustainable Development Fund Grant Program (PECO Territory)

Last DSIRE Review:	03/06/20033
Incentive Type:	Local Grant Program3
Eligible Technologies:	Passive Solar Space Heat, Solar Water Heat, Active Solar Space Heat,3 Solar Thermal Electric, Solar Thermal Process Heat, Photovoltaics, Landfill Gas, Wind, Biomass, Hydro, Fuel Cells, Geothermal Heat Pumps, Cogeneration
Applicable Sectors:	Commercial, Industrial, Construction, PECO Service Territory
Amount:	$25,000 average
Effective Date:	12/99
Website:	http://www.trfund.com/sdf/sdf_grants.htm

Summary:

The Sustainable Development Fund (SDF) was created by the Pennsylvania Public Utility Commission in its final order in the PECO Energy electric utility restructuring proceeding.

A group of environmental and consumer organizations known as the Environmentalists made the SDF a key element of their terms for settlement. Their vision was for the SDF to help make a sustainable energy future for southeastern Pennsylvania by growing a renewable and clean energy infrastructure in the region.

SDF received additional funding and responsibilities as a result of the PECO Energy/ Unicom merger settlement. That settlement added funding for new wind development, solar photovoltaics, and renewable energy education, as well as a lump-sum payment and an increase in SDF's core fund.

As a result of these two proceedings, SDF's total funding is approximately $32 million.

Four types of grants are available:

1. Sustainable Energy Business Planning Grants are available to businesses located in the PECO Energy Service territory that design, manufacture, sell, install, operate, or service renewable energy or energy efficiency products, technologies or services. The Sustainable Energy Business Planning Grants are available for business planning.

2. Sustainable Energy Business Start-Up Grants are available to businesses located in the PECO Energy territory that design, manufacture, sell, install, operate, or service renewable energy or energy efficiency products, technologies or services. These grants are available for:

    a) product/technology prototypes;
    b) product/technology demonstrations;
    c) measurement and metering costs;
    d) marketing efforts; and
    e) other business expansion/start-up costs.

3. Green Building Design Grants are available to architectural firms, engineering firms, building developers, and building owners that are committed to designing and building green buildings in the PECO Energy service territory. These grants are available to fund building energy simulation modeling using DOE2, PowerDOE, and similar computer simulation software.

4. The Sustainable Development Fund reserves the right to accept other grant proposals for work of compelling interest and value that strongly advances the Fund's mission of promoting renewable energy, energy conservation, and sustainable energy businesses.

As stated in the SDF's annual program plan, the sustainable energy grants are expected to average approximately $25,000 each over the course of the annual budget period. Grant funds are available for up to 75% of the cost of the work, with a minimum of 25% of the project costs being provided by the applicant. The average grant amount and the percentage of matching share are suggested values that may be modified by the SDF in special instances. For business planning grants, an additional guideline is that no more than 50% of the grant award may go to cover the costs of the applicant's staff.

West Penn Power SEF Grant Program

Last DSIRE Review:	03/06/20033
Incentive Type:	Local Grant Program3
Eligible Technologies:	Solar Water Heat, Active Solar Space Heat, Solar Thermal Electric,3 Solar Thermal Process Heat, Photovoltaics, Wind, Biomass, Hydro, Fuel Cells, Cogeneration
Applicable Sectors:	Nonprofit, Schools, West Penn Power Service Territory
Max. Limit:	$25,000
Date Enacted:	5/21/99
Effective Date:	5/01
Website:	http://www.wppsef.org/grants.shtml

Summary:

The West Penn Power Sustainable Energy Fund (WPPSEF) promotes the use of renewable energy and clean energy among commercial, industrial, institutional, and residential customers in the West Penn market region. Eligible projects include energy produced from solar, wind, low-impact hydro, and sustainable biomass (such as closed-loop biomass and biomass gasification). Clean energy refers to advanced technologies (such as fuel cells) that use fossil fuels but have significantly lower emissions and waste than current commercial4 ized technologies and fuels derived from waste.

Grants are available to non-profit companies and community-based organizations. Many of these grants will be leveraged with other grants from foundations and other funding agencies, and will lead to additional financing requests involving other WPPSEF products. Some of the potential uses of WPPSEF grants may include:

1.7 Demonstration projects and technologies incorporating renewable or energy efficiency products and services.

2.7 Engaging national programs. WPPSEF grants should be highly leveraged whenever possible.

3. Consumer education on renewable energy and energy conservation and efficiency.

4.7 Policy development. Specific policy research and initiatives that open markets for companies that become WPPSEF financing prospects could be supported.

A brief history...

In December 1996, Pennsylvania enacted the Electricity Generation Customer Choice and Competition Act (Customer Choice Act) to restructure the electric industry in the Commonwealth and to create a competitive market based on consumer choice in order to lower energy rates, enhance energy reliability, and provide a cleaner environment in the Com4 monwealth.

Restructuring plans were submitted to the Pennsylvania Public Utility Commission (PUC) and hearings were conducted. On November 19, 1998, the PUC granted final approval to the amended West Penn restructuring plan, which included the provision to establish a sustainable energy fund to help the Commonwealth shift toward greater reliance on renewable energy resources to meet its energy needs and to spur the development of the renewable energy sector as an important source of future economic growth in Pennsylva4 nia.

On May 21, 1999, the PUC approved the Board of Directors for the West Penn Power Sustainable Energy Fund (WPPSEF). The Board represents West Penn industrials, the environmentalists, the consumers, and the renewable/cleaner energy industry. The Fund was incorporated as a non-profit 501(c)3 organization and its by-laws were approved on June 2, 2000. A strategic alliance was established with The Economic Growth Connection of Westmoreland (EGC), an economic development organization, to provide regional business contacts, marketing and business development services, and financial completion of the deal flow. In December 2000, the WPPSEF Board competitively selected The Energy Institute of Penn State University, in partnership with Energetics, Incorporated, to adminis4 ter the fund and advance the public interest. PNC Bank was chosen to manage the non-invested assets.

Ohio

Net Metering: Yes

Tax Exemptions

Conversion Facilities Tax Exemption

Last DSIRE Review:	02/25/20033
Incentive Type:	Corporate Exemption, Property Tax Exemption, Sales Tax Exemption3
Eligible Technologies:	Solar Thermal Electric, Photovoltaics, Wind, Biomass, Renewable3 Transportation Fuels, Waste
Applicable Sectors:	Commercial, Industrial
Amount:	All
Max. Limit:	None
Terms:	All years upon certification
Date Enacted:	1978
Effective Date:	1978
Website:	http://www.odod.state.oh.us/cdd/oee/c_i_cfe.htm
Authority 1:	ORC § 5709.45--5709.53

Summary:

This statute exempts certain equipment from property taxation, Ohio's sales and use tax, and Ohio's franchise tax, where applicable. Originally enacted in 1978, this incentive has had some impact in the promotion of renewable energy in Ohio, according to the Ohio Office of Energy Efficiency.

The code applies to tangible property used in energy conversion, thermal efficiency im4 provements, and solid waste energy conversion. Generally, "conversion" refers to the replacement of fossil fuel sources of energy with alternative fuels or technologies; "thermal efficiency improvements" refers to the recovery of waste heat or steam produced in any commercial or industrial processes; and "solid waste conversion" refers to the use of waste to produce energy AND the utilization of such energy. Eligible technologies include solar thermal systems, photovoltaic systems, wind, biomass, and waste recovery systems.

Upon receipt of certification from the tax commissioner, such property is exempt from Ohio's sales and use taxes. In addition, such equipment improvements cannot be consid4 ered an improvement on land for purposes of property taxation, and they are not consid4 ered in the assessment of Ohio's franchise tax.

Corporate Tax Credit

Ethanol Investment Tax Credit - Corporate

Last DSIRE Review:	08/16/20023
Incentive Type:	Corporate Tax Credit3
Eligible Technologies:	Renewable Transportation Fuels3
Applicable Sectors:	Commercial, Industrial3
Amount:	50% of sum invested3
Max. Limit:	$5,000 per taxpayer per certified ethanol plant3
Date Enacted:	3/21/023
Effective Date:	tax year 20033
Expiration Date:	tax year 20133
Website:	http://lsc.state.oh.us/analyses/fnla124.nsf/3 All%20Bills%20and%20Resolutions/51ca
Authority 1:	Am. Sub. S.B. 144

Summary:

In March 2002, Ohio Governor Bob Taft signed into law SB 144, establishing the Ethanol Incentive Board and creating a tax credit against corporation franchise or income tax liability for investments in ethanol plants whose business plans have been approved by the Board. The law also promulgates that ethanol plants are air quality facilities eligible for Ohio Air Quality Development Authority financing. (However, the law declares that it is not an unfair or deceptive consumer sales practice to fail to disclose a blending of ethanol into gasoline.) In order to be eligible, facilities to be constructed and operated must be majority-owned by Ohio farmers prior to the first day the facility commences production.

Beginning in tax year 2003 and ending in tax year 2013, there is a nonrefundable tax credit for corporate taxpayers that invests in certified ethanol plants. The amount of the credit equals 50% of the amount the taxpayer invests in the plant, not to exceed $5,000 per taxpayer per certified ethanol plant (regardless of the number of years in which the tax-payer makes investments). The corporate credit should be claimed in the tax year immedi4 ately following the calendar year in which the investment was made.

Any credit amount in excess of the tax due may be carried forward for three tax years, but the amount of the excess credit allowed in any such year must be deducted from the balance carried forward to the next year.

North Carolina

Net Metering: No

North Carolina has a solar energy tax credit equal to 35% of the capital cost of renewable energy systems. Industrial firms are eligible for the tax credits. The renewable energy technologies eligible for North Carolina tax incentives include the following:

- Hot Water and Active Space Heating;
- Passive Solar Energy Systems;
- Solar Thermal and Solar Thermal Electric Applications;
- Solar Electric Applications;
- Solar Daylighting Systems;
- Wind Resources;
- Hydroelectric Resources; and
- Biomass Resources.

Tax Credits for Industrial Purchasers of Renewable Energy Technology

Renewable energy is energy derived from solar radiation, vegetation, organic wastes, mov4 ing water, or wind. Renewable energy does not include energy from nuclear reactions or fossil fuels. Renewable energy property is equipment that uses the renewable energy sources listed above to heat or cool buildings; to produce hot water, thermal, or process heat; or to generate electricity.

To promote and encourage the conservation of non-renewable energy through the increased use of renewable energy, the 1977 session of the North Carolina General Assembly enacted legislation that provided tax incentives in the form of a tax credit for the construc4 tion or installation of a solar energy system to heat, cool, or provide hot water to a building in North Carolina. Throughout the years, other tax credits encouraging investment in renewable energy sources were enacted. These included installation of a hydroelectric generator; installation of solar energy equipment for the production of heat or electricity in manufacturing or service processes of a person's business; installation of a wind energy device; and construction of a methanol gas facility. These credits were statutorily provided in both the corporation and individual income tax laws and had different calculation methods and maximum credit amounts.

The 1999 session of the General Assembly repealed the various tax credits in the corpora4 tion and individual income tax laws and recodified those provisions into one credit for investing in renewable energy property. The credit is codified in G. S. 105-129.16A, which is part of Article 3B of Chapter 105 of the North Carolina General Statutes. The different kinds of technologies that qualify for the renewable energy credit are subject to the same calculation percentage but the ceilings that apply to renewable energy property serving nonresidential property are different than those that apply to renewable energy property serving residential property. Also, because the credit is included in Article 3B, the allowable credit may not exceed 50% of the taxpayer's tax liability for the year reduced by the sum of all other credits. Corporations may elect to apply the credit against either the income tax or the franchise tax. The election must be made in the first year in which an installment of the credit is claimed and is binding for all future installments or carry forwards of that credit.

Provisions of the Tax Credit (G. S. 105-129.16A)

The tax credit for investing in renewable energy property is equal to 35% of the cost of renewable energy property constructed, purchased, or leased by a taxpayer and placed into service in North Carolina during the taxable year. If the property serves a single-family dwelling, the credit is taken for the taxable year in which the property is placed in service. For all other property, the credit is taken in five equal installments beginning with the year the property is placed in service.

The credit is subject to various ceilings depend4 ing on whether the renewable energy equip4 ment serves nonresidential property or residen4 tial property and, for residential property, the kind of renewable energy technology being used. The chart on on the right provides an overview of the different kinds of renewable energy technologies and the ceilings that apply to each.

Solar Energy Equipment for	Credit Limit for Commercial and Industrial Renewable Energy Technology
Solar Electric	$250,000 per installation
Solar Daylighting	$250,000 per installation
Solar Thermal Applications	$250,000 per installation
Service Water Heating	$250,000 per installation
Active Space Heating	$250,000 per installation
Wind	$250,000 per installation
Biomass	$250,000 per installation
Hydroelectric	$250,000 per installation

The credit can be taken against franchise tax; income tax; or, if the taxpayer is an insurance company, against the gross premiums tax. The allowable credit cannot exceed 50% of the taxpayer's tax liability for the year reduced by the sum of all other credits. The unused portion of the credit may be carried over for the next five succeeding years. The credit expires, and any remaining installments of the credit cannot be claimed if the property is disposed of, taken out of service, or moved out of the state during the 5-year installment period.

The allowable credit is calculated on Form NC-478G and the amount eligible to be claimed as a credit for the current year is carried to Form NC-478. Form NC-478 is used to deter- mine if the credit is reduced because it exceeds the 50% of tax less other credits limitation and for corporations to elect whether the credit is to be claimed against franchise tax or income tax.

The tax credit is allowable only to a person who owns the system or who first leases a building constructed or modified for sale in which a renewable energy system is con4 structed or installed. A taxpayer may not take a credit for property the taxpayer leases from another unless the taxpayer obtains the lessor's written certification that the lessor will not claim a credit with respect to the property. A taxpayer claiming a tax credit for investing in renewable energy equipment must designate the type of renewable energy system installed on Form NC-478G. Only one credit is allowed per system, regardless of the number of subsequent owners or persons leasing the building. Renewable energy equipment costs eligible for the tax credit include the cost of the equipment and associated design, con4 struction costs, and installation costs less any discounts, rebates, advertising, installation assistance credits, name referral allowances, or other similar reductions paid to the owner of the system as an inducement to purchase the renewable energy system. The cost of repairs to an existing system will not qualify for any additional credit; however, increases in capacity to an existing system may qualify for a new credit. All of the cost of new equip4 ment added to an existing system to increase capacity is eligible for the credit.

When replacing equipment in a system increases the capacity of that system, and a credit has previously been claimed for the system, a percentage of the cost of the replacement equipment is eligible for the tax credit. The allowable percentage is calculated by dividing the increase in project capacity by the project capacity after the replacement. If a credit has not previously been claimed for the system and the replacement of equipment results in an increased project capacity, 100% of the cost of the replacement equipment qualifies for the credit.

To qualify for the tax credit, a renewable energy system must conform to all applicable state and local codes and the requirements of all inspecting jurisdictions. The intent of the credit is to encourage the installation and use of equipment that takes advantage of a renewable energy resource such as solar energy. Systems that only incidentally incorporate renewable energy to sell other products do not qualify for the credit.

A system is not a renewable energy system for purposes of the tax credit until it is installed and fully functional. If an individual has paid for the system, but it is not yet installed and available for use during the year, no credit is allowed until the year in which the system is placed in service.

Tax Credit for Manufacturers of Renewable Energy Equipment

North Carolina also has a tax credit available for companies that build a plant to manufac4 ture renewable energy property. The renewable energy equipment facility tax credit is found in G. S. 105-130.28. The law became effective for tax years beginning on or after January 1, 2000. The credit is allowed only against corporate income tax and is equal to 25% of the installation and equipment costs of construction. If a glass manufacturing company invested to make renewable energy-related products in North Carolina, it could claim this credit for that particular operation. Information is available from the North Carolina Corporate, Excise, & Insurance Tax Division.

For renewable energy property installed on industrial facilities, the credit is taken in five equal installments beginning with the year the property is placed in service.

Contact Information

Corporate, Excise, & Insurance Tax Division3
P.O. Box 8713
Raleigh, North Carolina 27602-08713
Tel: (919) 733-85103

Texas

Net Metering: Yes

The State of Texas provides tax incentives for businesses that install renewable energy technologies. The incentives apply to the franchise taxes that corporations pay. The franchise tax is Texas's equivalent to a corporate tax; their primary elements are the same.

The form of the incentive is a tax deduction that can be taken for the following renewable energy technologies:

- Passive Solar Space Heating;
- Solar Water Heating;
- Active Solar Space Heating;
- Solar Electric, Photovoltaic Systems;
- Wind; and
- Biomass.

There is no maximum limit on the amount of the deduction. The authority for the incen4 tives is found in Texas Statutes and Codes 2F@171.107

This statute allows a corporation to deduct the cost of a solar energy device in one of two ways:

1. 100% of the system cost may be deducted from the company's taxable capital; or

2. 10% of the system's cost may be deducted from the company's income.

Both taxable capital and company income are taxed under the franchise tax.

Texas also offers a franchise tax exemption for manufacturers of photovoltaic systems.

Net Metering

Net metering is ordered by the Public Utility Commission of Texas under Substantive Rules, Section 23.66(f)(4), which became effective in 1986. The order requires utilities to offer a net metering option to Qualifying Facilities of 50 kW in size or less that use renewable energy resources to generate power.

Utilities must install a single meter for such customers and allow the meter to turn backward to register the net energy consumption or production by the customers. Net con4 sumption is billed at the applicable tariff and excess generation by the customers during a billing cycle is purchased by utilities at the avoided cost (fuel cost only, no capacity compo4 nent).

Texas initiated the net metering program 10 years ago to promote small wind power and photovoltaics in the market in the state. There is no statewide limit on the number of customers or total capacity under the net metering program.

Contact Information

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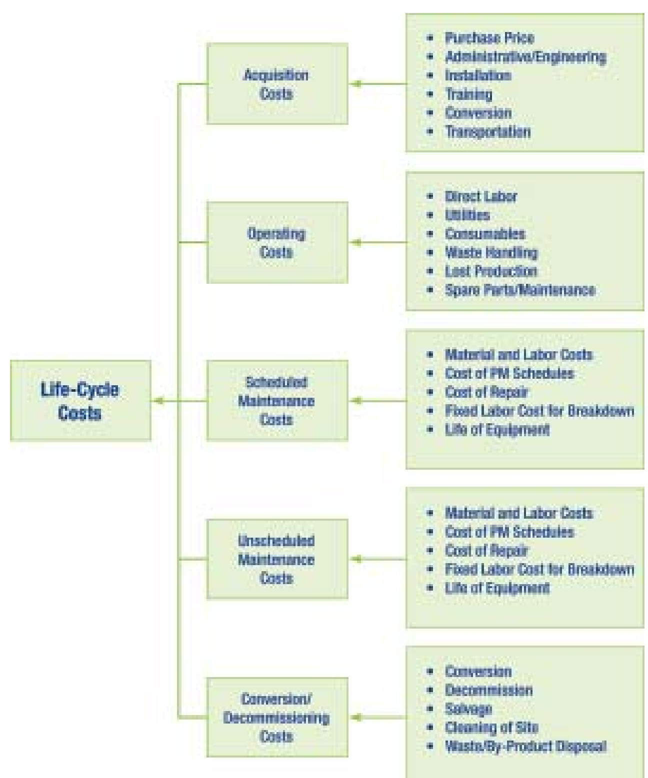
Website: http://www.seco.cpa.state.tx.us3

Life-Cycle Costs

A first step to implementing an industrial project is to determine if the project merits a share of the amount of available corporate capital. The "competition" manager must decide among all the options available to enhance product yields and capacity, improve product quality, cut energy costs, improve safety, and abate pollution. Financial managers commonly use results from *Simple Payback* and *Net Present Value* analysis to evaluate com4 peting projects. These methods enable decision-makers to compare proposed projects based on the required capital investment and the estimated benefits from the process changes, energy efficiency gains, and related financial benefits (e.g., depreciation and tax benefits).

Simple payback is the point in time when the sum of the investment is equaled by the cash flow that occurs from savings. Simple payback does not take into account the time value of money. It is used most often because corpora43 tions usually avoid investing in energy efficiency3 projects that do not return the investment cost3 in less than 10 to 24 months. When such short3 time horizons are used, simple payback reduces3 the risk because the time period when the corpo43 ration capital is at risk is kept short by defini43 tion.3

Life-Cycle Cost Components



Applying simple payback is not ideal when3 alternative projects involve financing and tax3 treatment because the analysis gets more compli43 cated and simplicity is lost. Simple payback will3 also skew results when the decision maker is3 choosing among mutually exclusive projects3 because size differences in project investment cost3 are not taken into account. Larger dollar returns3 could outweigh a smaller project that actually3 earned the company more for the amount of3 capital invested. Simple payback also makes it3 difficult to rank projects because it ignores3 returns after the payback of the original invest43 ment occurs.3

What simple payback analysis does do is give the3 corporation a concrete idea of how long its3 assumptions about the technology and savings3 estimates must hold to recover the amount of3 money spent on the technology. The drawback is that the focus of decision makers on the3 immediate term is very likely to bypass energy investments that have very good returns,3 returns that would more than justify the corporation going outside its normal capital or3 maintenance budgets to borrow money to finance the project.3

Net Present Value (NPV) is an assessment method that is better suited to compare mutually exclusive projects, especially when the projects vary substantially in the amount of capital that needs to be invested. NPV examines outflow and cash inflows together and accounts for the cost of money.

$$NPV = \sum_{n=0}^{n} \frac{F_0}{(1+d)^n} = F_0 + \frac{F_1}{(1+d)^1} + \frac{F_2}{(1+d)^2} + \Lambda + \frac{F_n}{(1+d)^n}$$

Where:

NPV = Net Present Value
Fn = net cash flow in year n
n = analysis period
d = annual discount rate

Net present value analysis takes into account the outgoing cash flow related to the invest4 ment and tracks the incoming cash flow in the form of energy savings. For each year evalu4 ated, investment and income analysis adds up the following items:

- Operation and Maintenance Costs;
- Revenues (i.e., energy savings);
- Depreciation;
- Net Taxable Income;
- Federal and State Income Taxes; and
- After Tax Cash Flow.

To support an NPV analysis that takes into account the cost of money, the manager must perform a life-cycle cost (LCC) analysis for the project.

An LCC analysis evaluates alternative capital investment opportunities from "cradle to grave." Life-cycle costing includes detailed analysis of the operations of the equipment to identify significant costs that would be overlooked in conventional analysis. This is what generates the after-tax cash flow, which is then adjusted by the selected discount rate that prevails for the corporation to account for opportunity costs. Many life-cycle cost studies have shown that over the lifetime of operating equipment, downstream costs, principally for fuel or electricity, will account for far more than the initial capital cost of the energy device.

An example of a simple payback analysis is the choice of using compact fluorescent light (CFL) bulbs versus incandescent lights. A CFL bulb costs about \$6.00 compared to an incandescent light bulb at about \$0.50. CFLs cost more but use one-third of the energy of the incandescent bulb while delivering the same amount of lumens. For any fixture that is on more than 8 hours per day, the investment cost for the more expensive CFL can be recovered in 6 to 10 months. Aside from savings in electricity consumption, a CFL bulb lasts up to 7,000 hours compared to 1,000 hours for an incandescent bulb. In a large facility, this would lead to significant savings in labor hours to change failed bulbs. Although incandescent bulbs would be chosen on an initial cost basis, a more rational eco4 nomic choice should be to employ CFL bulbs.

A sample model (SAE, 1993) in the figure lists components required for the analysis. It is important to note that life-cycle costing is essential for a realistic comparison of choices.

Conducting a proper life-cycle cost estimate is essential when projects using renewable energy systems are proposed. These systems qualify for government tax incentives and also reduce environmental emissions. These factors need to have dollar values assigned to them and be incorporated into the income net cash flow analysis. When comparing solar energy systems to fossil energy ones, care must be taken to understand the project performance assumptions for renewable energy systems. For instance, a solar thermal energy project will estimate the delivered energy cost for the solar system output. Typically, solar companies will provide a $/million Btu figure that includes everything that would be included in a life-cycle cost estimate, so the calculations are for energy delivered right into the load, which includes all thermal losses. Too frequently, comparisons with conventional fossil energy systems are made based on the cost of fuel and do not adequately take into account boiler and distribution system inefficiencies and operation and maintenance (O&M) costs for the conventional system. This acts as a barrier because prospective users of alternative energy systems will make a quick judgment based on fuel cost comparisons and reject any further consideration of the proposed project.

Based on best available data, the company staff need to estimate a schedule for such items as O&M costs during the lifetime of a piece of equipment. Due to the many assumptions required to be really precise, life-cycle cost analysis will create a close approximation of future costs that is consistent for the alternative choices. Several other key assumptions that must be made include the following.

Future Energy Costs

Predicting future energy costs has become more difficult in recent years because energy markets are less regulated and supply and demand balance for natural gas and petroleum in a more interconnected global economy is more susceptible to disruptions. Manufacturing corporations are having to become better energy market analysts and managers. While corporations may use long-term purchase or forward contracts and other options to hedge price fluctuations, it is rare that they will cover 100% of their energy supply needs through these mechanisms. In life-cycle costing for fossil fuel-based energy systems, energy cost estimates over time are critical since energy costs can, in most instances, be the largest lifetime cost element. Several escalation rates should be used in the analysis to check for energy cost sensitivity on the investment alternatives.

Mean Time Between Failure (MTBF)

MTBF is a measure developed from reliability engineering principles and statistical prob4 ability to estimate when a component will fail. The technical aspects of MTBF analysis is complex, but the results help predict when future labor, material, and downtime costs will occur to provide scheduled maintenance and overhauls as well as recover from unsched4 uled outages.

Scheduled Maintenance

Regular maintenance schedules can be developed based on recommendations available from equipment vendors. Using this information, the associated labor, material, and downtime costs can be estimated.

Unscheduled Maintenance

Unscheduled breakdowns can occur and should be worked into the life-cycle cost analysis based on the experience of the plant's staff, equipment vendors, or consultants. This assessment can be used to estimate additional, "unplanned" labor, material, and downtime costs.

Salvage Value

If a technology system is implemented and operational, the capital investment will be depreciated during the allowed period of time. More than likely, it will have very little value, or no value at the end of its usable life. A value should be assigned to the equip4 ment and factored into the LCC analysis.

The above are some, but not all, of the major factors that may be considered in a specific analysis. Each project will have its own unique characteristics, and it is important to assess the appropriate assumptions that apply.

The assumptions are very important to develop an accurate estimate of the lifetime costs of the alternatives being considered.

Appendix C

INTERNET RESOURCES

Appendix C: Internet Resources

Source: EIA Renewable Energy Information by Resource, Selected List of Internet Addresses

The list of addresses that follow are current as of June 2003. This list is abbreviated due to the great increase in Internet sites as well as the growing presence of links to associated web sites over the past few years. Therefore, this list should provide at least a useful start in a search for renewable energy information.

General: Renewables

U.S. Department of Energy (DOE), Energy Efficiency and Renewable Energy
www.eere.energy.gov

For information on DOE Renewable Energy Regional Offices
www.eere.energy.gov/rso.html

Energy Information Administration (EIA)
www.eia.doe.gov

North Carolina Solar Center
Renewable Energy State Incentives Database (co-sponsored by DOE)
www.ncsc.ncsu.edu

Center for Renewable Energy and Sustainable Technology (CREST)
www.crest.org

International Energy Agency (IEA)
CADDET International Information on Renewable Energy
www.caddet.co.uk

International Energy Agency (IEA)
Key World Energy Statistics
www.iea.org/techno/renew/index.htm

National Renewable Energy Laboratory (NREL)
Publications Database
www.nrel.gov/publications

National Association of Regulatory Utility Commissioners (NARUC)
www.naruc.org

California Energy Commission
www.energy.ca.gov

Green Energy News
www.nrglink.com

Renewable Resource Data Center
http://rredc.nrel.gov

U.S. Department of Energy Green Power Network
www.eere.energy.gov/greenpower

State Renewable Energy News
www.nrel.gov/analysis/sren

Interstate Renewable Energy Council
www.irecusa.org

Biomass: Wood

Regional Wood Energy Development Programme in Asia
www.rwedp.org

Forest Industry Network
World-wide directory of forestry, logging, harvesting, saw milling equipment, etc. companies and related information.
www.forestindustry.com

American Forest and Paper Association
www.afandpa.org

Biomass: Biofuels

Biofuels (Federal Government) Resources on the Internet
www.nal.usda.gov/ttic/biofuels.htm

DOE BioPower Information Program
www.eere.energy.gov/biopower/

DOE Alternative Fuels Data Center
www.afdc.doe.gov

DOE's National Biofuels Program
www.ott.doe.gov/biofuels

Short-Rotation Woody Crops (SRWC) Operations Working Group
A private and public partnership between wood products companies, equipment manufacturers, utility companies, the U.S. Forest Service, the U.S. Department of Energy's Oak Ridge National Laboratory (ORNL), the National Council of the Paper Industry for Air and Stream Improvement (NCASI) and university researchers
www.woodycrops.org

Municipal Solid Waste

Characterizations of Municipal Solid Waste in the United States 1997 Update
www.epa.gov/epaoswer/non-hw/muncpl/pubs/msw97rpt.pdf

U.S. Environmental Protection Agency, Office of Solid Waste
www.epa.gov/osw

The Solid Waste Association of North America
www.swana.org

Municipal Solid Waste Factbook
www.epa.gov/epaoswer/non-hw/muncpl/msw99.htm

Waste-to-Energy

Integrated Waste Services Association
www.wte.org

Geothermal

International Geothermal Association – U.S. DOE Sites
http://iga.igg.cnr.it/index.php

U.S. DOE/Geothermal Energy Technical Site
http://geothermal.id.doe.gov

Geo-Heat Center, Oregon Institute of Technology
Geothermal Information and Technology Transfer
http://geoheat.oit.edu

Geothermal Energy in California
www.energy.ca.gov/geothermal/

Geothermal Resources Council
www.geothermal.org

U.S. DOE Geothermal Energy Program
www.eere.energy.gov/geothermal/

Wind

Danish Wind Turbine Manufacturers Association
www.windpower.org

Wind Info Resources on the Net
www.afm.dtu.dk/wind/bookmark.html

British Wind Energy Association
www.bwea.com

European Wind Energy Association
www.ewea.org

German Wind Energy Association
www.wind-energie.de

German Wind Energy Institute
Wind Energy Use
www.dewi.de/statistics.html

RISO National Laboratory Denmark
Wind Energy & Atmospheric Physics Department
www.risoe.dk/vea

American Wind Energy Association
This comprehensive, up-to-date reference includes contact as well as product information.
www.awea.org

Windpower Monthly
www.wpm.co.nz

U.S. Dept. of Energy, Energy Efficiency and Renewable Energy Network (EREN)
Wind Energy Program
www.eere.energy.gov/RE/wind.html

National Renewable Energy Laboratory's National Wind Technology Center
www.nrel.gov/wind

Wind Powering America
www.eere.energy.gov/windpoweringamerica

Solar Energy

International Solar Energy Society
www.ises.org

Solar Thermal

ASME Solar Energy Division
www.asme.org/divisions/solar

Solar Energy
http://solstice.crest.org

Solar Radiation and Solar Thermal Systems
Optical Engineering Press
www.spie.org/web/abstracts/oepress/MS54.html

Sandia National Laboratories
National Solar Thermal Test Facility
www.sandia.gov/Renewable_Energy/solarthermal/nsttf.html

Solar Photovoltaic
NREL National Center For Photovoltaics
www.nrel.gov/ncpv

PV WEB SITES
www.pvpower.com/pvsites.html

Photovoltaic Module Businesses in the World
http://energy.sourceguides.com/businesses/byP/solar/pvM/pvM.shtml

Shell Solar
www.shell.com/solar

NASA Photovoltaic and Space Environment Effects Branch
http://powerweb.grc.nasa.gov/pvsee

Advancing Photovoltaic Technology at NREL's Outdoor Test Facility
www.nrel.gov/documents/otf.html

Million Solar Roofs Program
www.millionsolarroofs.org

Solar Electric Power Association
www.solaelectricpower.org

Sandia National Laboratories Photovoltaics Program
www.sandia.gov/pv

Photovoltaic News/ PV Energy Systems, Inc.
www.pvenergy.com

Fuel Cells

U.S. Department of Energy
Office of Fossil Energy, Advanced Power Systems
www.fe.doe.gov/coal_power/fuelcells/index.shtml

Hydrogen & Fuel Cell Investor Newsletter
www.h2fc.com

U.S. Fuel Cell Council
www.usfcc.com/

A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. By investing in technology breakthroughs today, our nation can look forward to a more resilient economy and secure future.

Far-reaching technology changes will be essential to America's energy future. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a portfolio of energy technologies that will:

- Conserve energy in the residential, commercial, industrial, government, and transportation sectors;
- Increase and diversify energy supply, with a focus on renewable domestic sources;
- Upgrade our national energy infrastructure; and
- Facilitate the emergence of hydrogen technologies as vital new "energy carrier's."

The Opportunities

Biomass Program
Using domestic, plant-derived resources to meet our fuel, power, and chemical needs

Building Technologies Program
Homes, schools, and businesses that use less energy, cost less to operate, and ultimately, generate as much power as they use

Distributed Energy & Electric Reliability Program
A more reliable energy infrastructure and reduced need for new power plants

Federal Energy Management Program
Leading by example, saving energy and taxpayer dollars in federal facilities

FreedomCAR & Vehicle Technologies Program
Less dependence on foreign oil, and eventual transition to an emissions-free, petroleum-free vehicle

Geothermal Technologies Program
Tapping the Earth's energy to meet our heat and power needs

Hydrogen, Fuel Cells & Infrastructure Technologies Program
Paving the way toward a hydrogen economy and net-zero carbon energy future

Industrial Technologies Program
Boosting the productivity and competitiveness of U.S. industry through improvements in energy and environmental performance

Solar Energy Technology Program
Utilizing the sun's natural energy to generate electricity and provide water and space heating

Weatherization & Intergovernmental Program
Accelerating the use of today's best energy-efficient and renewable technologies in homes, communities, and businesses

Wind & Hydropower Technologies Program
Harnessing America's abundant natural resources for clean power generation

Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

U.S. Department of Energy
Energy Efficiency and Renewable Energy